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THE UNIVERSITY OF ALBERTA

THE RECIPROCAL TAPPING PERFORMANCE OF EDUCABLE MENTALLY RETARDED BOYS

by

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A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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ABSTRACT

The purpose of the present study was to compare the reciprocal tapping performance of educable mentally retarded and non-retarded boys matched on the basis of mental age. Two mental age levels of approximately nine and eleven years were established within each intelligence group.

Welford's correction of Fitt's original index of difficulty equation was used to establish target information loads of three, four, and five bits. The boys reciprocally tapped at these target information loads under instructions for accuracy and speed. Analyses of variance were completed on the four dependent variables of rate of performance, seconds per hit, correct hits per second, and errors per second.

Under instructions for speed at all three target information loads the non-retarded boys reciprocally tapped more proficiently than the educable mentally retarded boys. In contrast, under instructions for accuracy under all three target information loads only the older non-retarded boys tapped more proficiently than their mentally retarded counterparts; at the younger mental age level no performance differences were found between the intelligence groups. Target information load did not differentially effect the two intelligence groups; however, instruction conditions did differentially effect the two intelligence groups as the older mental age non-retarded boys showed substantially superior reciprocal tapping performance under instructions for speed at all three target loads in comparison with the other subject groups. The older non-retarded boys showed clearly higher performance scores than their younger counterparts; no such developmental increase in performance was evident between the two age groups of adolescent mentally retarded boys. The results of the study were consistent with past comparative studies of fine-motor performance. Future comparative research studies to investigate possible differences in response strategies and corrective reaction time were suggested.

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Movement is essential for optimal human development. In their early years, children learn motor skills which enable them to explore, manipulate, and interact with their physical environment. As they grow older, they use motor skills within the play situation to learn appropriate social behaviours. Later, adequate motor proficiency facilitates the enjoyment of leisure-time activities and can be a significant factor in vocational success. Therefore, adequate motor performance is important in the lives of all people; however, it is especially important for mentally retarded persons who are limited in their cognitive-verbal abilities. In fact, the motor performance capabilites of the mentally retarded may determine their physical health status, opportunites for social interactions, and prospects of self-supporting vocational opportunities (Austin, 1968; Gold, 1973; Rarick, 1973). Acknowledgement of the importance of adequate motor performance has motivated many investigators to study this essential aspect of the lives of the mentally retarded.

Comparative studies of the motor performance of non-retarded and mentally retarded persons have generally resulted in significant group differences in favour of the non-retarded subjects. Using the Lincoln Adaptation of the Oseretsky Test of Motor Proficiency as the measure of motor performance, five investigators have reported significant group differences in favour of the non-retarded subjects (Sloan, 1951; Turnquist & Marzolf, 1954; Distefano, Ellis, & Sloan, 1958; Malpass, 1960; and Hofmeister, 1969). Rarick and his associates, using a variety of gross-motor performance batteries, have consistently reported deficiencies in the motor performance of both trainable and educable mentally retarded children when compared to non-retarded children (Francis & Rarick, 1959; Widdop, 1967; Rarick, Widdop, & Broadhead, 1970; Rarick & Dobbins, 1972).

A number of investigators, using widely different fine-motor tasks, have reported significant motor performance differences in favour of non-retarded over mentally retarded persons. The dependent variables employed in these studies included pegboard tasks (Cantor & Stacey, 1951; Annett, 1958; Knight, Atkinson & Hyman, 1967; Weaver & Ravaris, 1972), pursuit rotor tasks (Ellis & Sloan, 1957; Baumeister, Hawkins, & Hollard, 1966; Simenson, 1973), mirror drawing tasks (Reynolds & Stacey, 1955; Ellis, Barnett, & Pryer, 1957) and finger tapping tasks, (Knights, Atkinson, & Hyman, 1967; Weaver & Ravaris, 1972). In all of the above studies the mentally retarded were inferior in motor performance when compared to the non-retarded subjects. Some investigators have considered the effect of different levels of intellectual ability on motor performance. Cantor & Stacey (1951), Annett (1958), and Weaver & Ravaris (1972), reported lower motor performance scores with decreases in intelligence levels. Correlational studies between mental age and the motor performance scores of mentally retarded children have resulted in low positive correlations (Ellis & Sloan, 1957; Ellis, Barnett, & Pryer, 1957; Black & Davis, 1966; Knights, Atkinson & Hyman, 1967; Hofmeister, 1969).

An evaluation of the results of available studies on the motor performance of mentally retarded persons indicates that they are generally less proficient and more variable in their gross-motor and fine-motor performance when compared to non-retarded persons of the same age and sex.

Unfortunately, the specific perceptual-motor problems of mentally retarded persons have not been clearly delineated due to the inadequacies of the comparative motor tasks and research strategies used in the past (Bruininks, 1974; Wall, 1976). For instance, in the fine-motor performance research area, many investigators have had difficulty interpreting their results due to the use of comparative tasks which result in floor and ceiling effects. Furthermore, investigators have rarely manipulated the difficulty level of the motor tasks to assess the effect of such variation on the performance of the comparison groups; this information would be an important first step in comparative investigations. Finally, few investigators have used tasks that have sufficient information on the basic processes underlying the performance on them; therefore, when differences in performance are found the investigators have gained minimal understanding of the possible causes of the performance differences.

The basic purpose of this investigation is to obtain information on the reciprocal tapping performance of educable mentally retarded boys. These boys were selected as the subjects for this study because they were in the most prevalent category of mental retardation and their proficiency in fine-motor skills has important consequences for their future vocational opportunities. The ultimate thrust of this investigation is to obtain a better understanding of the factors that contribute to the fine-motor difficulties of the mentally retarded so that effective amelioration programs can be implemented.

As indicated above, past comparative motor performance research studies have not employed effective research strategies; hopefully, the present research design will change this situation. A number of research design factors must be considered if the information on performance differences on a fine-motor task is to add to our understanding of the motor performance of educable mentally retarded persons. The rationale for the research design of this investigation is based on decisions regarding the selection of the comparative task, the subject groups tested, and the task variables manipulated; a discussion of each of these factors follows.

The inherent difficulties in comparative research studies have been well documented (Baumeister, 1967; Berkson & Cantor, 1962; Ellis, 1969; Zigler, 1969). Valuable information can be obtained regarding the behavioural difficulties of the mentally retarded when comparative studies investigate the differential effects that the manipulation of task variables have on the performance of the different intelligence groups in a study (Baumeister, 1967; Clarke & Clarke, 1973). Therefore, the starting point of this investigation was the selection of an appropriate comparative task that would provide specific information on the fine motor performance of both intelligence groups.

A number of reasons made the perceptual-motor aiming task of reciprocally tapping with a stylus between two target plates an excellent comparative task for this study. Reciprocal tapping is a highly response-loaded task with minimal perceptual demands. It provides a suitable means for assessing movement control capabilities without the confounding effects associated with more highly perceptually-loaded fine-motor tasks. Through the use of Fitt's Law; there is a quantifiable means for systematically increasing task demands (Fitts, 1954; Welford, 1968). The dependent variables used to measure performance on the task eliminate the problems of floor and ceiling effects and the ease with which the task demands can be manipulated facilitate the study of possible interactions between specified levels of task difficulty and different intelligence groups. A considerable amount of descriptive research has been completed on the reciprocal tapping task with both adults and children (Fitts, 1954; Fitts & Radford, 1966; Connolly, 1968; Welford, Norris, & Shock, 1969; Kerr, 1975). Initial research has been conducted on the component processes underlying reciprocal tapping performance (Posner, 1969; Ells, 1973; Beggs & Howarth, 1970; Megaw, 1975; Roediger, Knight, & Kantowitz, 1977). If differences are found between different subject groups on this task, then this basic research information could provide valuable guidance for future research efforts investigating the processes responsible for these performance differences. Finally, the reciprocal tapping task has potential use as a part of a vocational assessment battery. The performance of specific individuals at different target information loads could be used to match people more accurately to realistic fine-motor task demands in the work situation.

A fundamental issue in behavioural research with educable mentally retarded children is whether or not mental retardation should be viewed as a developmental lag or as a result of differences inherent within the mentally retarded person. Difference theorists ascribe lower retardate performance to specific deficits in the component processes underlying performance (Brown, 1973; Ellis, 1963; Das, 1970).

The developmental lag theorists purport that differences in favour of the non-retarded subjects in most chronological-age matched comparative studies are due to the higher mental ages of the non-retarded subjects (Zigler, 1969). Thus a critical test of the developmental lag hypothesis would be to demonstrate that non-retarded boys exhibit superior reciprocal tapping performance in comparison to mental-age matched mentally retarded boys even when the latter group have marked advantages in physiological maturation and past learning experiences. If the non-retarded boys do in fact exhibit better reciprocal tapping performance then an analysis of the differences in the central processes underlying the reciprocal tapping task should be investigated rather than attributing the performance differences solely to extrinsic factors. Therefore, in order to challenge directly the developmental lag theoretical position the mental age match research paradigm was selected for use in this study. In order to note the effect of an increase in mental age, two levels of mental age were included from each intelligence group. Boys with mental ages of approximately nine and eleven years were included in the research design. Therefore, fine-motor performance differences due to increases in mental age could be studied within the groups as well as between the intelligence groups.

The use of the reciprocal tapping task facilitated the manipulation of a number of task variables which were included to investigate performance differences between the subject groups. Target information load and instructional set have proven to be important task variables in adult reciprocal tapping studies (Fitts, 1954, Fitts & Radford, 1956; Welford, Norris & Shock, 1969). Therefore, these task variables were included along with testing sequence and trials in the design of this study.

Target information load was varied by employing three logarithmically increasing task conditions which were obtained by employing Welford's correction (1960) of Fitts' original (1954) index of task difficulty. The amplitude of the task was held constant at eight inches over the three target widths of .286, .523, and 1.07 inches; therefore, the target information load for the three conditions were 5, 4, and 3 bits.

The second task variable focused on the effect of two different instruction conditions. The first condition was tapping for accuracy in which the subjects attempted to hit the target plates as fast as possible but under the instruction that they be as accurate as possible. The second instruction condition emphasized speed of tapping performance with little emphasis on the accuracy of the performance. The instructions for the subjects are presented in Appendix B.

The third task variable was testing sequence; it was included to investigate the effect of the order of presentation of the three target information loads on the subjects. In order to limit the required testing time, only two presentation orders were included in the study, a hard and easy testing sequence. The hard testing sequence began with the most difficult five bit target load, followed by the four and three bit target loads; the easy testing sequence was in reverse order.

The final task variable was the five trials within each of the six different task conditions.

The purpose of this study was to obtain information on the following questions:

1. Do the non-retarded boys exhibit better reciprocal tapping performance than their mental-age matched mentally retarded counterparts?
2. Do the older mental age boys in each intelligence classification exhibit better reciprocal tapping performance than their younger mental age counterparts?
3. Do the levels within the task factors of target information load, testing sequence, and instruction conditions differentially effect the

reciprocal tapping performance of the two intelligence groups at the different levels of mental age?

METHOD

Subjects

Forty educable mentally retarded and 40 non-retarded right handed boys were the subjects of this study. The mentally retarded boys were students at a special vocational school administered by the Edmonton Public School Board. The non-retarded boys were pupils in two elementary schools under the jurisdiction of the same Board.

Permission to test the subjects was received from the Principal of the Vocational School and from the parents of the elementary school children. The Wechsler Intelligence Scale for Children full scale scores were used to classify the mentally retarded boys. The results of the Lorge-Thorndike Intelligence test were used to classify the non-retarded boys. The preferred writing hand was used to categorize the subjects as right-handed. Any boy with a chronic medical difficulty, physical disability, or behavioural difficulty was removed from the tentative list of subjects. A table of random numbers was used to select randomly the eight groups of ten boys to meet the requirements of the experimental design.

Research design

A mental age match design was used in this study. Younger and older mental age groups were formed from a tentative list of suitable boys in both intelligence classifications. These four groups were randomly divided into easy and hard testing sequence groups which resulted in eight groups of 10 boys. The resulting research design consisted of two classifications of intelligence, two levels of mental age, two testing sequences, three target information loads, two instruction conditions and five trials. The general format of the analysis of variance used to analyse the four dependent variables of seconds per hit, correct hits per second, errors per second, and rate of performance is presented in Table 1.

The means and standard deviations for CA, MA, and IQ level for the eight subject groups are presented in Table 2. Statistical analyses were completed to establish the effectiveness of the matching procedures. The analysis of variance on the mental age scores of the younger and older mental age groups for both testing sequence and intelligence groups resulted in no significant differences. Furthermore, the t-tests on the intelligence scores and chronological ages of the subjects in the easy and hard testing sequence groups within the two mental age classifications also resulted in no significant differences.

Apparatus

The reciprocal tapping apparatus was placed on a solid wood table with a surface area of 30" x 60" at a height of 30 inches. (See Figure 1). An adjustable chair was used to seat each subject comfortably in front of the apparatus. The major feature of the apparatus was the use of three pairs of interchangeable blue steel target plates which were machine-milled to widths of .286, .523, and 1.07 inches. The distance between the centres of each pair of target plates was held constant at eight inches by the use of three brass filler plates, of varying widths, that were used as the centre of the target fields. The resulting target information loads were five, four, and three bits as indicated in the section on target information load.

Each target plate had eight .25 inch error plates located on each

Table 1

General Format for the Analysis of Variance - Main Effects*

Source of Variation	k	df	Error term	df of error term	Results describe effects of
Intelligence (Q)	2	1	P(QAS)	72	Intelligence differences
Mental Age (A)	2	1	P(QAS)	72	Mental age differences
Testing Sequence (S)	2	1	P(QAS)	72	Testing sequences
Instructions (I)	2	1	PI(QAS)	72	Instruction conditions
Target Load (L)	3	2	PL(QAS)	144	Target information load
Trials (T)	5	4	PT(QAS)	288	Five trials at each load
Subjects (P)	10 (within cells)				

All factors are fixed, except subjects.

Table 2

Mean Chronological Age, Intelligence Quotient, and Mental Age for the Eight Subject Groups (n=10)

Younger Mental Age

		Retarded			Non-retarded		
		CA	IQ	MA	CA	IQ	MA
Testing Sequence	Easy	13.9	67.5	9.41	8.72	111.3	9.66
	Hard	13.8	67.7	9.35	8.78	109.9	9.63

Older Mental Age

		Retarded			Non-retarded		
		CA	IQ	MA	CA	IQ	MA
Testing Sequence	Easy	17.1	66.3	11.3	10.88	108.8	11.73
	Hard	17.2	65.4	11.2	10.78	105.1	11.30

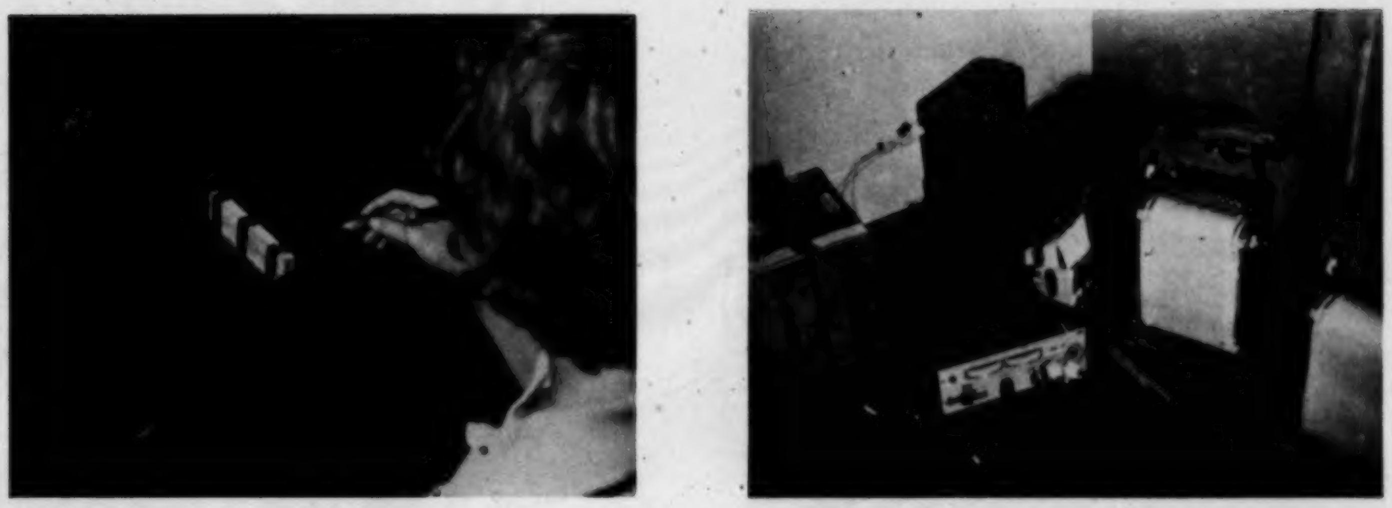

Figure 1. The Reciprocal Tapping Test Apparatus

side of them. The target and error plates were separated by extremely thin non-conducting plastic sheets; these were cut to fit exactly between each of the plates which resulted in a smooth target and error plate surface. The target, error, and centre filler plates were held together by a constricting frame consisting of two ½ inch steel end-plates that were tightened by two steel bolts at the top and bottom of the frame. In order to change the target information load, the two steel bolts were loosened and the appropriate center and target plates were replaced; the tightening of the constricting frame ensured precise target information loads. The target field and frame was fitted into a ½" plywood frame that was 8 x 20 inches. A brown 14" x 36" vinyl cover, with a window cut out of it to allow only the target and error plates to show through, was used to mask the constricting frame of the apparatus.

The subjects reciprocally tapped with an eight inch tapping stylus which consisted of a solid brass rod, rounded at the end, insulated within a ¼ inch wooden dowel. The tapping stylus had a light wire connecting it to a common lead which completed a circuit from a specific target or error plate to a given channel on two Easterbrook event recorders.

The circuit was powered by a six volt portable power generator; individual resistors controlled the current flow to each of the marker pens. The target and error plates were connected to the event recorders by individual leads from set screws at the end of each target or error plate. An automatic switching relay allowed only one event to be recorded on the graph paper from each side of the target field; thus eliminating the possibility of the tapping stylus sliding across a number of error plates and confounding the number of hits recorded during a given aiming attempt.

The timing of each fifteen second trial was controlled by a continuously audible 250 Hertz sine wave sound that was provided by an Eico audio generator. The sound was amplified by a Bogen Challenger amplifier through an 8 watt portable speaker. A Hunter decade interval timer provided a closed circuit to the audio generator for a set fifteen second period. Another Hunter interval timer, initiated by the experimenter by a push button switch, controlled an amber warning light located on the 3½ foot high plywood board that separated the subject from the experimenter and recording and timing apparatus. The warning light was situated directly in front of the subject; eight inches above the tapping area. The Hunter interval timer provided a precise three second warning period and then automatically started the fifteen second performance sound that was controlled by the other Hunter interval timer. The subject placed the tapping stylus on the right hand side target plate during the three second warning period prior to the start of each trial.

Four dependent variables were used to measure the reciprocal tapping performance of the subjects. The first dependent variable was the seconds per hit time which was calculated by dividing the number of hits recorded on the target and error plates during a fifteen second trial into fifteen. The second dependent variable was the index of correct hits per second. It was calculated by summing the number of hits recorded on the two target plates and dividing this result by fifteen. The index of number of errors per second was the third dependent variable. It was calculated by summing the number of hits recorded on the error plates on each side of the target plates and dividing the result by the fifteen seconds of trial time. The rate of performance was the fourth dependent variable used in this study. It was calculated by the method recently employed by Beggs, Graham, Monk, Shaw, and Howorth (1972).

The effective target width was calculated by using the root mean square of the hits measured in inches for each trial.

It was assumed that the distribution of hits around each target was normally distributed so that the root mean square value was treated as the equivalent of the standard deviation of hits; then, by referring to the table of the normal distribution, the 4.13 units of standard deviation was obtained, and used in the following formula to obtain the index of difficulty: $ID = \log_2 ((8/(4.13 RMS)) +.5)$.

The raw data were transformed into the above dependent variables by the following procedure. Each target and error plate was given a specific location on the event recorder graph paper. Two seventeen channel event recorders were used; each channel represented a specific distance from the target plate to each of the error plates surrounding it. The number of hits recorded on each graph paper channel for a fifteen second trial was scored; and the total punched, at a given field position, on a computer card. SPSS data transformation programs were used to generate the four dependent variables.

Procedure

The testing session occurred as follows. The subject was met at the school counselling office and guided to the testing room. During the walk to the test room the subject was informed that he would be performing on some special testing equipment and would receive his choice of one chocolate bar at the end of the session. The subject was seated on an adjustable chair so that he was comfortably seated in front of the test apparatus. The test apparatus was set with the three bit target load plates in position. The subject was then read the following general instructions and asked if he had any questions:

"This is a machine that sees how fast you can hit these targets. You have to hit the targets one after another with this tapper. When this light goes on put the tapper on this target and get ready to start tapping. This sound (tone pressed for subjects to hear) will go on when you should start tapping the targets. Keep tapping until the sound that you hear stops."

The subject was given the wired tapper and was administered three practice trials under the instructions for accuracy. (Appendix B). At the end of the three trials the subject was asked again if he had any questions. The experimenter monitored the subject's performance by way of the hit marks on the recording graphs and an unobtrusive mirror. If the performance indicated that the subject understood what was required of him the actual testing began. All subjects had no difficulty understanding what was expected of them in each task.

During the formal testing session, each block of five trials for a given condition was conducted as follows. The experimenter placed the appropriate target plates in position. The instructions for accuracy were given prior to the first trial. The subject placed the wired tapper on the right hand side target plate when the warning light was illuminated. Three seconds after the warning light appeared a continuous sound was generated for a set fifteen second period; during this time the subject reciprocally tapped attempting to hit the two target plates. At the end of the fifteen second performance period the buzzer stopped and the event recorder automatically marked the end of the trial. The five trials under each testing condition were conducted in the above manner; however, between each of the target information load levels the target plates were changed. This procedure took approximately one minute during which time an individual timer provided the time control for starting the next testing condition within the sixty second time limit. The instructions for accuracy or speed were read prior to the appropriate performance period. Instructions for accuracy and speed were blocked so that each subject performed five trials at each target load under the accuracy condition and then under the speed instruction condition resulting in thirty fifteen second performance trials. The total testing session was completed usually within twenty-seven minutes.

The testing of the subjects was completed over a four week period. The actual testing was conducted on four days of each test week; approximately three subjects were tested each day. Using a table of random numbers, the boys were assigned randomly into a testing order. If a boy was absent he was tested at the end of the testing order when he returned to school. The testing of the educable mentally retarded boys at L.Y.Cairns Vocational School was completed during the first and last weeks; while the non-retarded boys at Hazeldean and Holyrood schools were tested during the second, and third weeks respectively.

RESULTS

Four dependent variables were used to evaluate the reciprocal tapping performance of the subjects in this study. The primary dependent variable was the rate of performance of the subjects; supplementary information on their reciprocal tapping performance was obtained from the number of correct hits per second, the number of errors per second, and the seconds per hit dependent variables.

The results for each of the dependent variables are presented in four separate sections; each section includes sub-sections on specific results related to subject variables (intelligence level and mental age) and task variables (target information load, testing sequence, instruction conditions and trials). Significant interactions among subject and task variables are presented under the most appropriate sub-section, based on the nature of the interaction. Throughout the chapter, to facilitate the interpretation of the results, the higher-order interactions are presented followed by lower-order interactions and the qualified main effects. The complete analysis of variance summary tables for each dependent variable are included in Appendix B. Inasmuch as this developmental-comparative study of reciprocal tapping performance was the first to systematically investigate the effects of the selected task variables, the probability level accepted for significance was set at $p \leq .05$.

Rate of performance

Subject variables: Intelligence level and mental age.

The two major organismic variables in this study were intelligence level and mental age. The analysis of variance for the rate of performance dependent variable resulted in a number of significant interactions involving the above two subject variables and certain task variables (Appendix B).

Intelligence level, mental age and instructions.

One of the most important interactions of the above type was the significant three-way interaction among intelligence level, mental age, and instruction conditions ($F\ (1,72) = 7.17$, $p \leq .01$). Table 3

Table 3

Simple Effects Tests for ROP Means Within the Significant Interaction of IQ, MA, and Instructions

Source	S.S.	d.f.	M.S.	F.
IQ x MA x I	383.42	1,72	383.42	7.17*
IQ x MA at I_1	394.91	1,144	394.91	6.30*
IQ x MA at I_2	52.86	1,144	52.86	.84

*$p \leq .05$

summarizes the results of the simple effects tests on this interaction; as Figure 2 graphically illustrates, the significant ordinal interaction was located within the accuracy instruction condition (F (1,144) = 6.301, $p \leq .01$). The results of the tests on the rate of performance means within the intelligence x mental age matrix under the accuracy instruction condition are presented in Table 4. These results indicate that under instructions for accuracy the older mental age group of non-retarded boys performed at a higher rate of performance, at all target information loads, than the older mental age group of mentally retarded boys; however, at the younger mental age level, there was no difference between the two intelligence groups. Furthermore, there were no significant differences in rate of performance between the two retardate mental age groups; but the older mental age group of non-retarded boys performed at a higher rate of performance than their younger counterparts.

The above analysis of the three-way interaction among intelligence level, mental age, and instruction condition qualifies the interpretation of the two significant subject main effects of intelligence level (F (1,72) = 5.743, $p \leq .05$) and mental age (F (1,72) = 4.492, $p \leq .05$.)

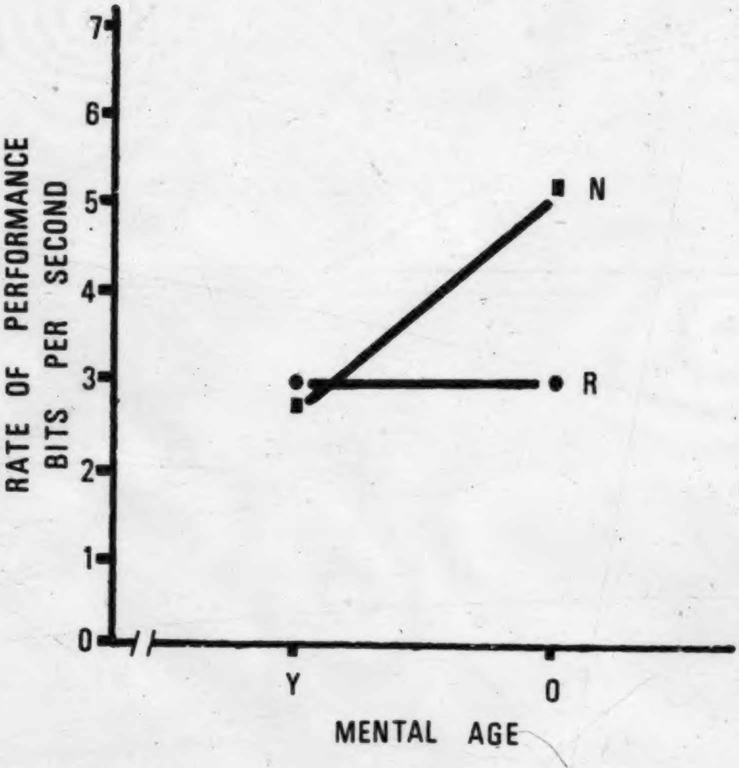

Figure 2. Mean ROP for IQ and MA Groups
under Instructions for Accuracy

The non-retarded boys at both mental ages have higher rates of performance at all targets loads than the mentally retarded boys of similar mental age under instructions for speed; however, as indicated above, this finding holds true only at the older mental age level under instructions for accuracy. The significant mental age main effect must also be interpreted with qualification as the older mental age retardates under instructions for accuracy did not have significantly higher rates of performance than their younger mental age counterparts.

Table 4

Tests on ROP Means for IQ and MA Groups Under Instructions for Accuracy

Intelligence Level	Means(bits/sec)
Retarded	
MA 9 (R9)	3.02
MA 11 (R11)	3.06
Non-retarded	
MA 9 (R9)	2.79
MA 11 (R11)	5.12
	F (1,144)
H1: R 9=R11	.004
H2: N11>N9	11.42*
H3: N 9=R9	.11
H4: N11>R11	8.88*

Task variables: Target information load, testing sequence, and instructions.

The three major task variables manipulated in this study were target information load, testing sequence, and instruction conditions. Again, the analysis of variance resulted in a number of higher-order interactions among task and subject variables.

Mental age, target information load, testing sequence, and instructions.

The four-way significant interaction among mental age, target information load, testing sequence, and instruction conditions was analyzed initially on the basis of instruction conditions. The results of the two sets of simple effects tests are presented in Table 5 ; as indicated in this table, the significant interaction is located within the accuracy instruction condition. The remaining mental age x target load x testing sequence interaction within the accuracy instruction condition was analysed on the basis of target load. A significant interaction was found only within the three bit target information load. The rate of performance means for the four mental age groups, under instructions for accuracy, at each target information load under the two testing sequences are presented graphically in Figure 3 . As

Table 5

Simple Effects Tests for ROP Means Within the Significant Interaction of MA, Target Load, Testing Sequence and Instructions

Source	S.S.	d.f.	M.S.	F
MA x L x S x I	163.60	2,144	81.80	4.183*
MA x L x S at I_1	337.70	1,288	337.70	17.35*
MA x L x S at I_2	32.60	1,288	32.60	1.68
MA x S at I_1L_1	1412.56	1,216	1412.56	15.48*
MA x S at I_1L_2	69.30	1,216	69.30	.76
MA x S at I_1L_3	45.72	1,216	45.72	.50.

*p = .05

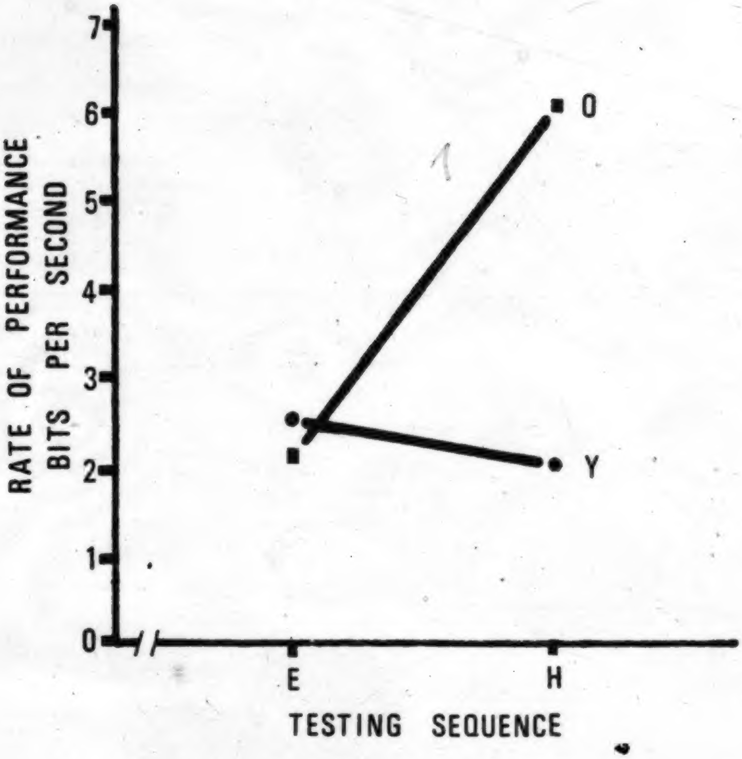

Figure 3. Mean ROP for MA Groups at 3 Bit Target Load under 2 Testing Sequences with Instructions for Accuracy.

seen in Table 6 , the older mental age groups who performed under the hard testing sequence at the easiest three bit target load had higher rates of performance than their mental age counterparts who performed under the easy testing sequence as well as both testing sequence groups at the younger mental age level.

Table 6

Tests on ROP Means for MA Groups Under Different Testing Sequences at the 3 Bit Target Load Under Instructions for Accuracy

Mental Ages	Means(Bits/Second)
MA 9	
Easy Sequence (E9)	2.42
Hard Sequence (H9)	2.00
MA 11	
Easy Sequence (E11)	2.16
Hard Sequence (H11)	6.09
	F (1,216)
H1: E9=H9	1.35
H2: H11>E11	125.33*
H3: E11=E9	1.35
H4: H11>H9	129.73*

*$p \leq .05$

Mental age, target information load, and testing sequence. The isolated effects within the above four-way interaction directly effected the significant target information x testing sequence x mental age interaction. Table 7 summarizes the simple effects test results for this interaction. Again, the interaction can be attributed to the three bit target load. As seen in Table 8, the simple effects tests on the rate of performance means are exactly the same as those found within the four-way interaction described above; clearly, this three way interaction is due to the much greater rate of performance of the older mental age groups who performed

Table 7

Simple Effects Tests for ROP Means Within the Significant Interaction of MA, Load, and Testing Sequence

Source	S.S.	d.f.	M.S.	F
MA x L x S	206.31	2,144	103.16	5.33*
MA x S at L_1	330.75	1,216	330.75	9.00*
MA x S at L_2	3.66	1,216	3.66	.09
MA x S at L_3	99.48	1,216	99.48	2.70

*$p \leq .05$

under the hard testing sequence and obtained such relatively high rates of performance under instructions for accuracy at the three bit target information load.

Target information load and testing sequence.

The above higher-order interactions must be considered when interpreting the significant interaction between target information load and testing sequence (F (1,216) = 6.118, $p \leq .05$). The results of the tests on the rate of performance means within this interaction are presented in Table 9 and graphically displayed in Figure 4 ; the boys in the hard testing sequence group obtained higher rates of performance than the boys in the easy testing sequence group at the three bit target load; however, testing sequence had no effect at the other two target information loads. This significant interaction at the three bit target load can be attributed largely to the higher-order interaction effects, associated with testing sequence, delineated above.

Table 8

Tests on ROP Means for MA Groups Under 2 Testing Sequences at the 3 Bit Target Information Load

Testing Sequence	Means (Bits/Second)
MA 9	
Easy Sequence (E9)	4.15
Hard Sequence (H9)	3.91
MA 11	
Easy Sequence (E11)	4.00
Hard Sequence (H11)	6.36

	F (1,216)
H1: E9=H9	.10
H2: H11>E11	9.12*
H3: E11=E9	.04
H4: H11>H9	9.93*

*$p \le .05$

The relatively lower rate of performance of the boys in the easy testing sequence groups at the three bit target load resulted in no significant differences across the three target information loads. There were clear differences between the three and four, and three and five bit target loads under the hard testing sequence.

Table 9

Tests on ROP Means for Three Target Loads Under 2 Testing Sequences

Testing Sequences	Means(Bits/Second)
Easy Sequence	
3 Bit Load (E3)	4.07
4 Bit Load (E4)	4.36
5 Bit Load (E5)	3.98
Hard Sequence	
3 Bit Load (H3)	5.14
4 Bit Load (H4)	4.08
5 Bit Load (H5)	3.26

	F (1,216;1,288)
H1: H3>E3	6.12*
H2: H4=E4	.42
H3: H5=E5	2.79
H4: E4=E3	.92
H5: E5=E4	1.21
H6: E5=E3	.30
H7: H3=H4	3.40
H8: H4=H5	2.62
H9: H3>H5	6.01*

*$p \leq .05$

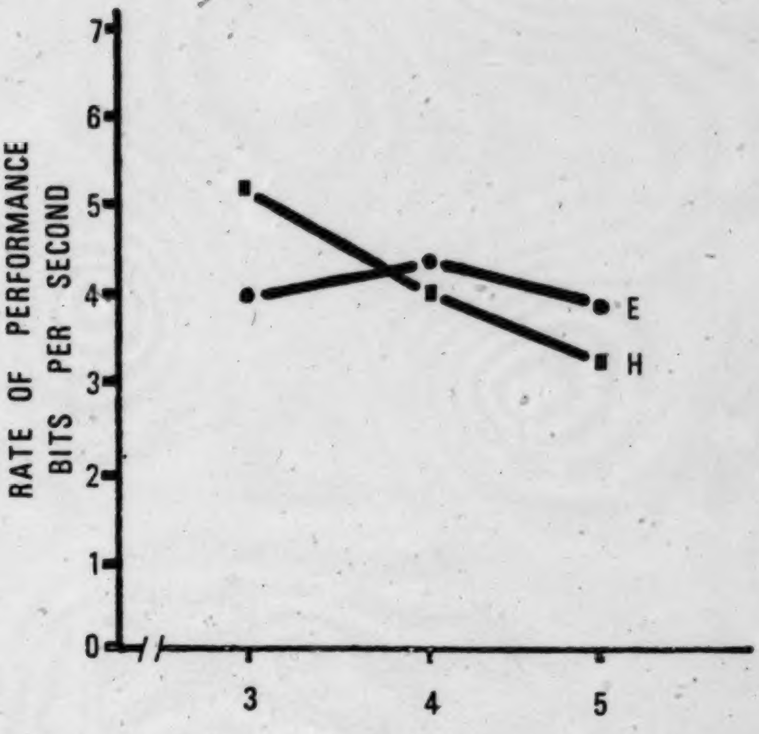

Figure 4. Mean ROP at 3 Target Loads
Under 2 Testing Sequences

Target information load and instructions.

The above interactions influence the interpretations of the significant interaction between target information load and instruction conditions (F (2,144) = 20.617, p ≤ .01). The results of the test on means within this significant interaction are presented in Table10, and graphically displayed in Figure 5. There are distinctly higher rates of performance when the boys performed under instructions for speed at the three and four bit target loads; no differences in the rate of performance was found at the five bit target load under the two instruction conditions.

Table 10

Tests on ROP Means for 3 Target Loads Under Instructions For Accuracy and Speed

Instructions	Means(Bits/Second)
Accuracy	
3 Bit Load (A3)	3.17
4 Bit Load (A4)	3.75
5 Bit Load (A5)	3.57
Speed	
3 Bit Load (S3)	6.04
4 Bit Load (S4)	4.69
5 Bit Load (S5)	3.67
	F (1,216;1,288)
H1: S3>A3	7.31*
H2: S4>A4	5.72*
H3: S5=A5	.06
H4: S3>S4	4.33*
H5: S3>S5	7.59*
H6: S4=S5	3.26
H7: A3=A4	1.86
H8: A3=A5	1.29
H9: A4=A5	.56

*$p \leq .05$

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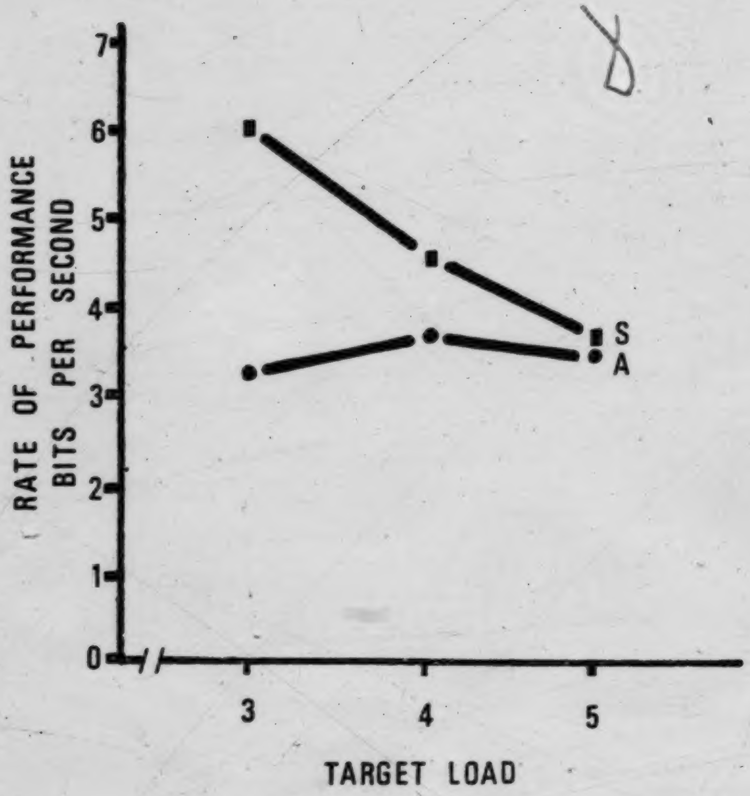

Figure 5. Mean ROP at 3 Target Loads Under Instructions for Accuracy and Speed

The differential effects of the mental age x testing sequence x target information load x instruction conditions interaction influenced the effects of target information load under the two instruction conditions. The lower rates of performance of the younger mental age boys, in both testing sequence groups, and the older mental age boys in the easy testing sequence group contributed to the finding of no differences in rate of performance across the three target information loads under instructions for accuracy. Under instructions for speed, there were differences in the rate of performance between the three and four, and three and five bit target loads under instructions for speed.

The main effect for target information load was significant ($\underline{F}$ (2,144) = 10.119 $\underline{p} \leq .01$). The results of the Tukey tests on the rate of performance means across target information load are presented in Table 11. A significant difference in rate of performance was found only between the three and five bit target loads; however, the effect of the higher-order interactions involved with target information load discussed above must be considered when interpreting this result.

The main effect for instruction conditions was significant; however, the significant interactions associated with it also qualify this result ($\underline{F}$ (1,172) = 19.033, $p \leq .01$).

Table 11

Tests on ROP Means for Three Target Loads

Target Load	Means (Bits/Second)
3 Bit Load (L3)	4.61
4 Bit Load (L4)	4.22
5 Bit Load (L5)	3.62
	F (1,144)
H1: L4=L3	1.76
H2: L3>L5	4.48*
H3: L4=L5	2.71

*$p \leq .05$

Seconds per hit

Subject variables: Intelligence and mental age.

A significant interaction was found between intelligence level and mental age (F (1,72) = 6.23 $p \leq .05$). Figure 6 illustrates the ordinal interaction and the results of the simple effects tests on it are displayed in Table 12. Only at the older mental age level was the seconds per hit time of the non-retarded boys faster than their retarded counterparts. Furthermore, there were no significant differences in the seconds per hit time between the two mental age groups of mentally retarded boys; however, within the non-retarded boys, the older mental age group performed significantly faster than the younger group.

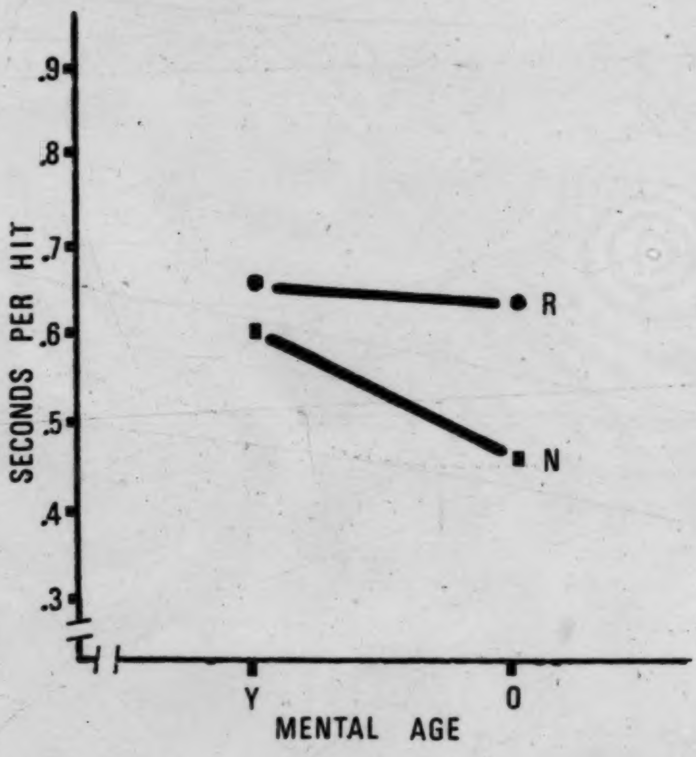

Figure 6. SPH Means for IQ
Groups at 2 MA Levels

Table 12

Tests on SPH Means for IQ Groups at 2 Levels of MA

Intelligence Level	Means (Seconds/hit)
Retarded	
MA9 (R9)	.652
MA11 (R11)	.635
Non-retarded	
MA9 (N9	.607
MA11 (N11)	.460
	F(1,144)
H1: R9=R11	.238
H2: N9>N11	16.145*
H3: N9=R9	1.574
H4: R11>N11	22.896*

*$p < .05$

The main effect for intelligence was significant indicating that the non-retarded boys performed faster over all conditions than did the mentally retarded boys (F (1, 72) = 18 2.5, $p < .01$); furthermore, the significant mental age main effect indicated that the older mental age boys of both intelligence groups performed the tapping task faster than their younger mental age counterparts. The ordinal interaction between intelligence level and mental age qualifies to a limited degree the above results.

Task variables; Target information load, testing sequence, and instructions.

Intelligence, target information load, and instructions.

The significant intelligence x target information load x instructions interaction was analysed initially on the basis of instruction conditions ($F(2,144) = 7.80$, $p \leq .01$); the simple effects test results presented in Tables 13 and 14 indicate that the significant interaction occurred within the accuracy instruction condition. As illustrated in Figure 7, significantly faster times were obtained by the non-retarded boys under instructions for accuracy at all three target information loads; furthermore, the seconds per hit time increased with each successive increase in target load for both intelligence groups. The significant ordinal interaction was due to the greater increase in performance time of the mentally retarded boys performing under instructions for accuracy at the five bit target information load.

Table 13

Simple Effects Tests for SPH Means Within the Significant Interaction of IQ, Target Load, and Instructions

Source	S.S.	d.f.	M.S.	F
IQ x L x I	.17	2,144	.09	7.80*
IQ x L at I_1	.73	1,216	.73	5.22*
IQ x L at I_2	.05	1,216	.05	.38

*$p \leq .05$

Table 14

Tests on SPH Means For IQ Groups at 3 Target Loads

Under Instructions for Accuracy

Intelligence Level	Means(Seconds/hit)
Retarded	
3 Bit Load (R3)	.63
4 Bit Load (R4)	.73
5 Bit Load (R5)	.86
Non-retarded	
3 Bit Load (N3)	.54
4 Bit Load (N4)	.61
5 Bit Load (N5)	.69
	F (1,216;1,288)
H1: R3>N3	4.96*
H2: R4>N4	9.99*
H3: R5>N5	20.09*
H4: R5>R3	17.94*
H5: R5>R4	9.92*
H6: R4>R3	8.02*
H7: N5>N3	6.03*
H8: N5>N4	5.27*
H9: N4>N3	11.30*

*$p \leq .05$

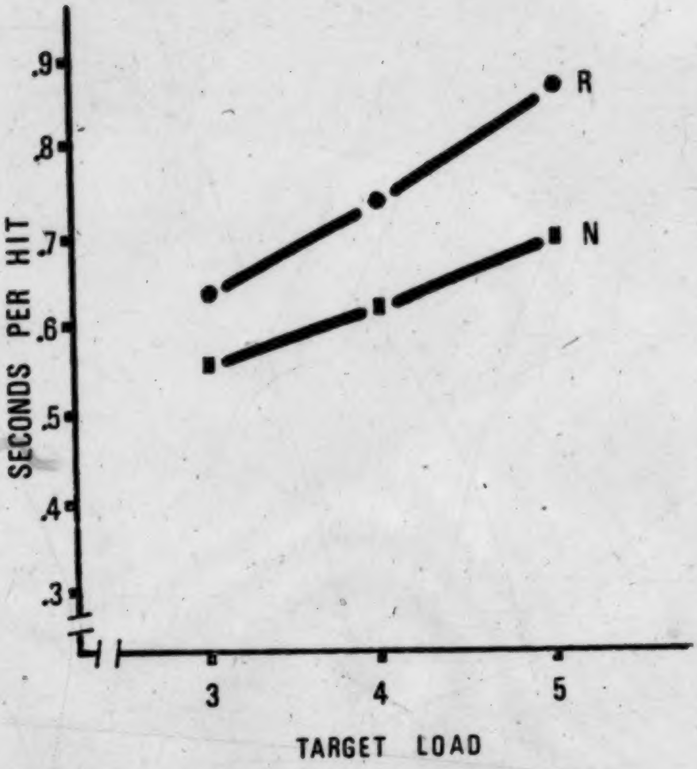

Figure 7. Mean SPH for the 2 IQ Groups at 3 Target Loads Under Instructions for Accuracy

Target information load and instructions.

The target information load x instruction conditions interaction was significant (F (2,144) = 22.458, p ≤ .01); as presented in Table 15 and illustrated in Figure 8, significant differences in seconds per hit time were found between the two instruction conditions at all three target information loads. The non-linear increase in performace time under instructions for accuracy at the five bit target load produced the significant ordinal interaction; however, the slower times of the retarded boys under instructions for accuracy at the five bit target information load contributed substantially to this effect.

Table 15

Tests on SPH Means for 3 Target Loads Under Instructions for Speed and Accuracy

Instructions	Means (Seconds/hit)
Accuracy	
3 Bit Load (A3)	.59
4 Bit Load (A4)	.67
5 Bit Load (A5)	.78
Speed	
3 Bit Load (S3)	.44
4 Bit Load (S4)	.50
5 Bit Load (S5)	.56

	F(1,216;1,288)
H1: A3>S3	199.00*
H2: A4>S4	15.76*
H3: A5>S5	417.02*
H4: A5>A3	17.89*
H5: A5>A4	9.79*
H6: A4>A3	8.11*
H7: S5>S3	13.37*
H8: S5>S4	5.14*
H9: S4>S3	6.45*

*$p \leq .05$

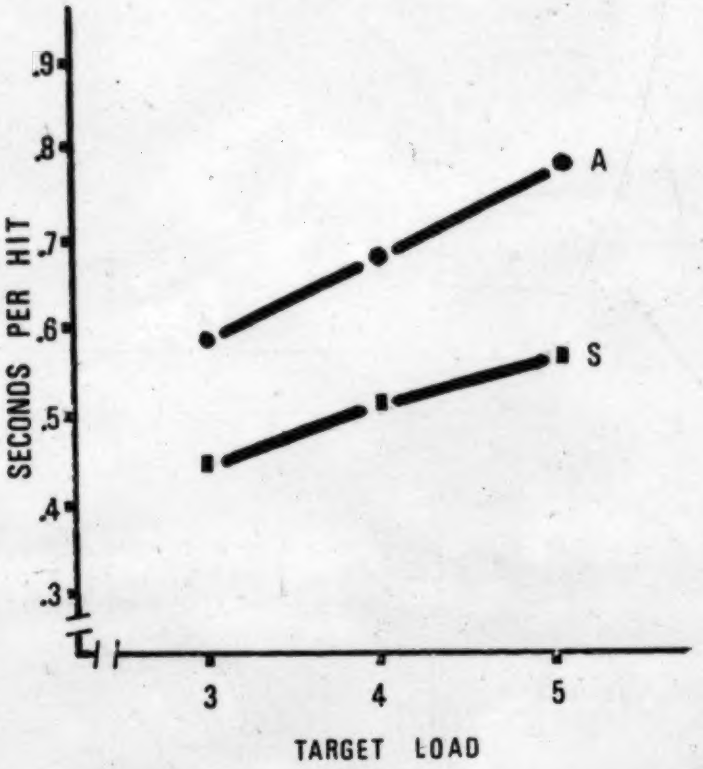

Figure 8. Mean SPH for 3 Target Loads Under
Instructions for Accuracy and Speed

Target information load, testing sequence, and mental age.

The significant target information load x testing sequence x mental age interaction was analysed initially on the basis of target information load (*F*(2,144) = 5.3.6, p < .01); as seen in Table 16 the interaction was significant only under the five bit target load condition. As presented in Table 17 and illustrated in Figure 9, the older mental age boys in both intelligence groups who performed under the easy testing sequence, in which they met the most difficult target load last, performed significantly faster at the five bit target load than their mental age counterparts who performed under the reversed hard testing sequence.

Table 16

Simple Effects Tests for SPH Means Within the Significant Interaction of MA, Target Load, and Presentation Sequence

Source	S.S.	d.f.	M.S.	F
MA x L x S	.25	2,144	.13	5.32*
MA x S at L_1	.08	1,288	.08	3.42
MA x S at L_2	.05	1,288	.05	2.14
MA x S at L_3	.24	1,288	.24	10.26*

*$p \leq .05$

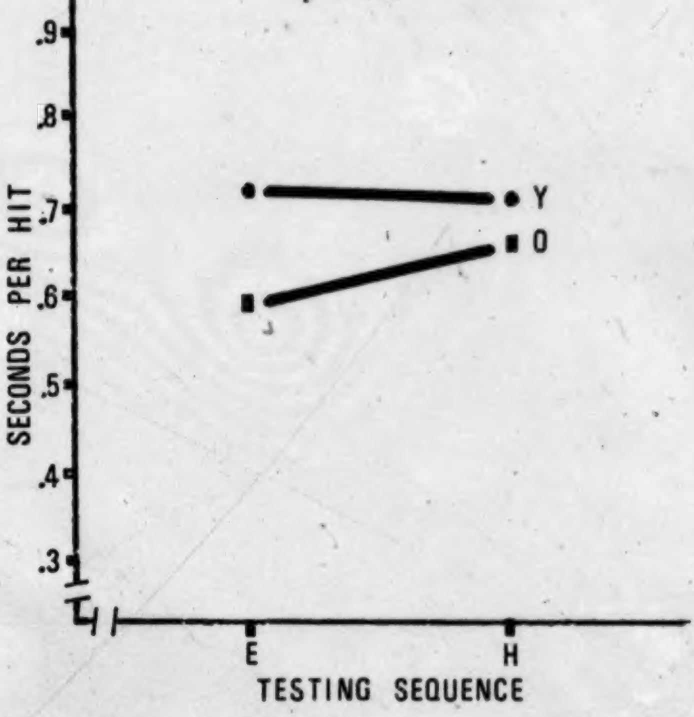

Figure 9. Mean SPH for MA Groups Under 2 Testing Sequences at the 5 Bit Target Load

Table 17

Tests on SPH Means for MA Groups at the 5 Bit Target Load

Under Two Testing Sequences

MA Level	Means (Seconds per hit)
MA 9	
Easy Sequence (E9)	.714
Hard Sequence (H9)	.708
MA 11	
Easy Sequence (E11)	.588
Hard Sequence (H11)	.660
	F (1,216)
H1:E9>E11	10.71*
H2:H9=H11	1.55
H3:H11>E11	3.50*
H4:H9=E9	.03

*$p < .05$

Target information load and testing sequence.

The above testing sequence effect was not sufficiently strong to produce significant differences in seconds per hit time at the five bit target load within the significant target information load x testing sequence interaction (F (2,144) = 15.440, $p < .01$). As seen in Figure 10 and supported by the simple effect results in Table 18, testing sequence had a significant effect on seconds per hit time only at the three bit target information load. The boys in the hard testing sequence

Table 18

Tests on SPH Means for 3 Target Loads Under 2 Testing Sequences

Testing Sequences	Means (Seconds/hit)
Easy Sequence	
3 Bit Load (E3)	.54
4 Bit Load (E4)	.59
5 Bit Load (E5)	.65
Hard Sequence	
3 Bit Load (H3)	.48
4 Bit Load (H4)	.58
5 Bit Load (H5)	.68

	F(1,216;1,288)
H1: E3>H3	3.77*
H2: E4=H4	.16
H3: H5=E5	1.46
H4: E5>E3	10.63*
H5: E5>E4	5.36*
H6: E4>E3	5.26*
H7: H5>H3	18.56*
H8: H5>H4	9.42*
H9: H4>H3	9.24*

*$p \le .05$

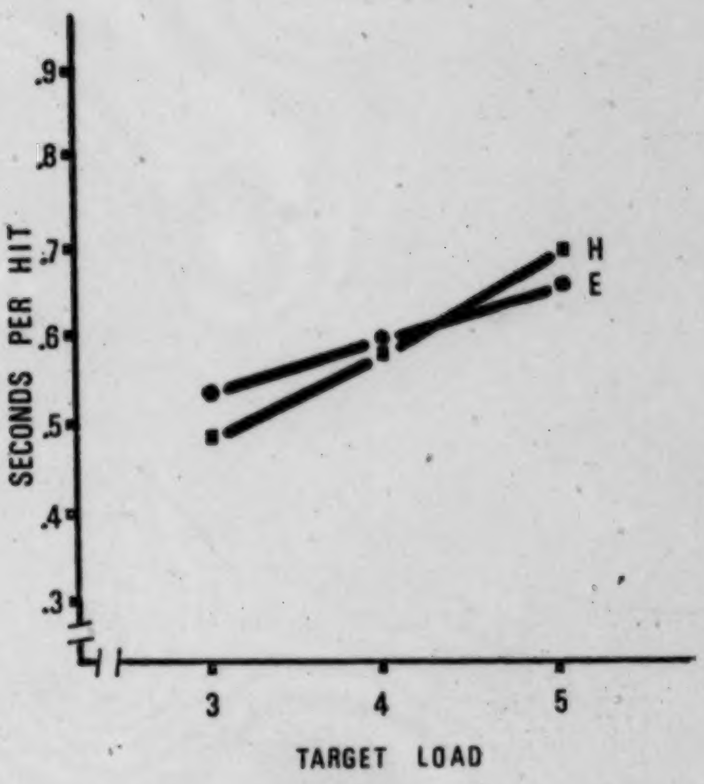

Figure 10. Mean SPH for 3 Target Loads Under 2 Testing Sequences

performed faster when they met the easiest three bit target load last than did their counterparts in the easy testing sequence group who performed on the easy target load first. There were significant increases in seconds per hit time with each increase in target information load for the boys in both testing sequence groups.

Target information load.

The main effect for target information load was highly significant ($\underline{F}(2,144) = 211.335, \underline{p} < .01$). The results of the Tukey tests on the second per hits means across target information load are presented in Table 19. Seconds per hits time increased with each successively more difficult increase in target information load.

Table 19

Tests on SPH Means for Three Target Loads

Target Load	Means(Seconds/hit)
3 Bit Load (L3)	.510
4 Bit Load (L4)	.588
5 Bit Load (L5)	.668
	F(1,144)
H1: L3>L5	20.69*
H2: L3>L4	10.20*
H3: L4>L5	10.44*

*p= .05

Instructions.

The main effect for instruction conditions was significant; the boys had faster tapping times under instructions for speed at all target information loads (F(1,72) = 362.225, p = .01).

Trials.

The main effect for trials was significant (F (4,288) = 16.691, p =.01). The results of the Tukey procedure on comparisons between all possible pairs of second per hits means are presented in Table 20. The performance time obtained by the boys on the fifth trial was significantly faster than that obtained on the first three trials and the fourth trial was significantly faster than that of the first two trials.

Table 20

Tests on SPH Means for Five Trials

Trials	Means (Seconds/hit)
Trial 1 (T1)	.60
Trial 2 (T2)	.59
Trial 3 (T3)	.59
Trial 4 (T4)	.58
Trial 5 (T5)	.58
	F(1,72)
H1: T5>T1	9.09*
H2: T5>T2	8.02*
H3: T5>T3	5.88*
H4: T5=T4	2.67
H5: T4>T1	6.42*
H6: T4>T2	5.35*
H7: T4=T3	3.21
H8: T3=T1	3.21
H9: T3=T2	2.16
H10: T2=T1	1.07

*$p < .05$

Correct hits per second

Subject variables; Intelligence level and mental age.

The three-way interaction among intelligence level, mental age, and instruction conditions was significant (*F* (1,72) = 6.0.7, $p \triangleq .05$); the results of the simple effects tests presented in Table 21 indicate that only the accuracy instruction condition was significant (*F* (2,144) = 16.771, $p \triangleq .01$). As presented in Table 22, the older mental age group of non-retarded boys performed more correct hits per second under instructions for accuracy than did their mentally retarded counterparts. Furthermore, there were no differences in the number of correct hits per second for the two retardate mental age groups; however, the older mental age group of non-retarded boys had more correct hits per second under the accuracy instruction condition than did their younger mental age counterparts.

Table 21

Simple Effects Tests for CHS Means Within the Significant Interaction of IQ, MA, and Instructions

Source	S.S.	d.f.	M.S.	F
IQ x MA x I	1.24	1,72	1,24	6.02*
IQ x MA at I_1	13.44	1,144	13.44	16.77*
IQ x MA at I_2	2.07	1,144	2.07	2.58

$^{*}p \triangleq .05$

Table 22

Tests on CHS Means for IQ and MA Groups

Under Instructions for Accuracy

Intelligence Level	Means(Correct hits/second)
Retarded	
MA9 (R9)	1.32
MA11 (R11)	1.30
Non-retarded	
MA9 (N9)	1.39
MA11 (N11)	1.70
	F (1,144)
H1: R9=R11	.035
H2: N11>N9	10.21*
H3: N9=R9	.51
H4: N11>R11	16.79*

*$p \leq .05$

Intelligence and mental age:

The results of the significant interaction between intelligence level and mental age are congruent with the results of the above three-way interaction (F (1,72) = 5.964, $p \leq .05$). As seen in Table 23 and illustrated in Figure 11, the older mental age non-retarded boys performed more correct hits per second than did their mentally retarded counterparts; whereas no differences were found between the two intelligence groups at the younger mental age level. This effect may be attributed to the greater number of correct hits per second that the older mental age non-retarded boys performed under instructions for

Table 23
Tests on CHS Means for IQ Groups
at 2 Levels of MA

Intelligence Level	Means (Correct hits/second)
Retarded	
MA9 (R9)	1.38
MA11 (R11)	1.38
Non-retarded	
MA9 (N9)	1.50
MA11 (N11)	1.73
	F (1,144)
H1: R9=R11	.00
H2: N11>N9	11.87*
H3: N9=R9	3.09
H4: N11>R11	27.25*

*$p \leq .05$

accuracy; however, the interaction is clearly ordinal in nature. Again, as in the above three-way interaction, no significant differences in the number of correct hits per second were found between the two mental age groups of mentally retarded boys; however, the older mental age group of non-retarded boys performed significantly better than their younger counterparts.

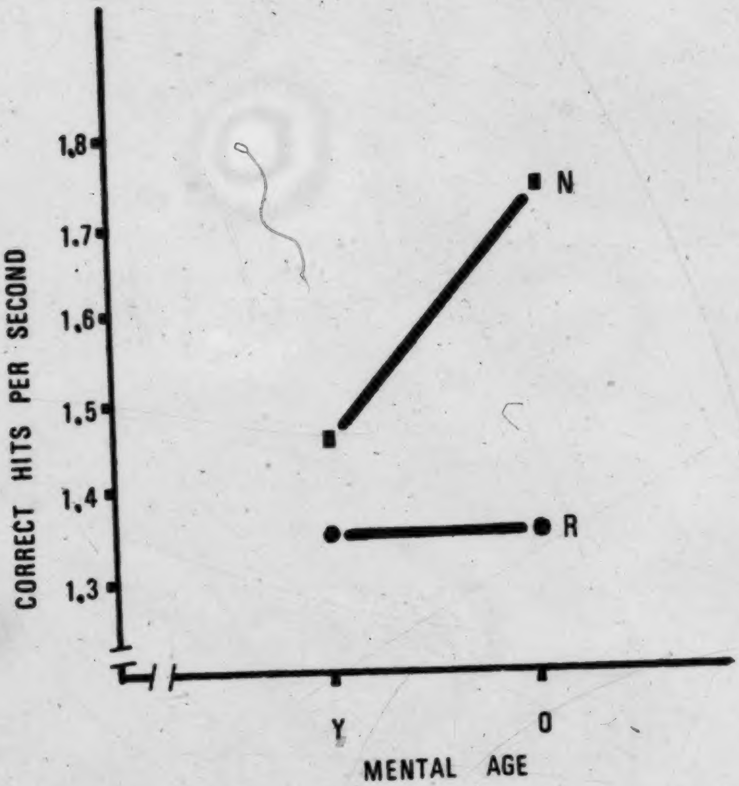

Figure 11. CHS Means for IQ Groups
at 2 MA Levels

Task variables: Target information load, testing sequence, and instructions.

The significant intelligence x target information x instructions interaction was analysed on the basis of instruction conditions (F (2,144) = 8.472, p < .01).

As shown in Figure 12, the simple effects test results displayed in Tables 24 and 25 indicate that the significant interaction occurred within the speed instruction condition. The non-retarded boys under instructions for speed had more correct hits per second than the mentally retarded boys under the three and four bit target loads; but not under the most difficult five bit target information load. The number of correct hits per second increased significantly under each successively more difficult target load for both intelligence groups.

Target information load and instructions.

The above three-way ordinal interaction was due to the isolated effects within the five bit target load under instructions for speed; therefore it has little influence on the significant interaction between target information load and instruction conditions (F (2,144)

Table 24

Simple Effects Tests for CHS Means Within the Significant Interaction of IQ, Target Load, and Instructions

Source	S.S.	d.f.	M.S.	F
IQ x L x I	1.37	2,144	.69	8.47*
IQ x L at I_1	.37	1,216	.37	.50
IQ x L at I_2	3.99	1,216	3.99	7.67*

*$p < .05$

Table 25

Tests on CHS Means for IQ Groups at 3 Target Loads

Under Instructions for Speed

Intelligence Level	Means (Hits/second)
Retarded	
3 Bit Load (R3)	1.92
4 Bit Load (R4)	1.39
5 Bit Load (R5)	1.03
Non-retarded	
3 Bit Load (N3)	2.29
4 Bit Load (N4)	1.62
5 Bit Load (N5)	1.16

	F(1,216;1,288)
H1: $N3>R3$	19.25*
H2: $N4>R4$	6.80*
H3: $N5=R5$	2.42
H4: $R3>R4$	10.63*
H5: $R3>R5$	18.00*
H6: $R4>R5$	7.37*
H7: $N3>N4$	13.64*
H8: $N3>N5$	22.83*
H9: $N4>N5$	9.19*

*$p \leq .05$

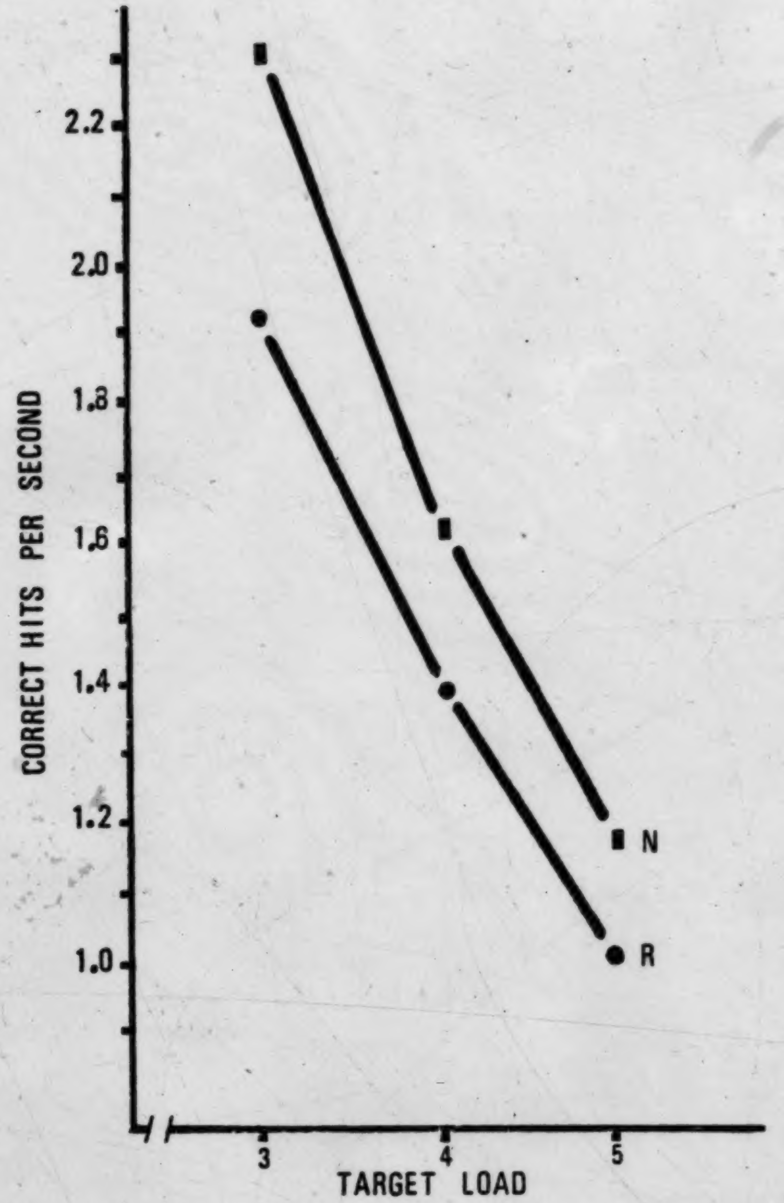

Figure 12. Mean CHS for IQ Groups at 3 Target Loads Under Instructions for Speed

= 94.642, p * .01). The simple effects tests in Table 26 indicate that the boys performed significantly more correct hits per second under instructions for speed at the three and four bit target loads but not under the most difficult five bit target load; furthermore, they

Table 26

Tests on CHS Means for Three Target Loads Under Instructions for Accuracy and Speed

Instructions	Means(Hits/Second)
Accuracy	
3 Bit Load (A3)	1.75
4 Bit Load (A4)	1.41
5 Bit Load (A5)	1.12
Speed	
3 Bit Load (S3)	2.10
4 Bit Load (S4)	1.50
5 Bit Load (S5)	1.09
	F(1,216;1,288)
H1: S3>A3	208.80*
H2: S4>A4	12.98*
H3: A5=S5	.94
H4: S3>S4	17.19*
H5: S3>S5	28.94*
H6: S4>S5	11.75*
H7: A3>A4	9.51*
H8: A3>A5	18.02*
H9: A4>A5	8.51*

*$p \leq .05$

performed less correct hits per second at each successively more difficult target load under both instruction conditions.

Target information load and testing sequence.

A significant interaction between target information load and testing sequence was found (F (2,144) = 4.303, $p \leq .05$). As seen in Table 27, the results of the simple effects tests show that the boys performing under the hard testing sequence, where the easiest target load was met last, had significantly more correct hits per second than the boys performing under the easy testing sequence only at the easiest three bit target load. The results of the Tukey procedures indicated that the boys performing under both testing sequences performed more correct hits per second with each successive decrease in task difficulty.

Target information load.

The above higher-order interactions involving testing sequence and instruction conditions do not modify the clear target information load main effects (F (2,144) = 331.260, $p \leq .01$); as the Tukey procedure results in Table 28 shows, the boys executed more correct hits per second with each decrease in target information load.

Instructions.

The significant main effect for instructions indicates that more correct hits per second were performed under instructions for speed (F (1,72) = 57.775, $p \leq .01$); however, as indicated above, this finding holds true for only the three and four bit target information loads.

Table 27

Tests on CHS Means for Three Target Loads Under Two Testing Sequences

Testing Sequence	Means(Hits/Second)
Easy Sequence	
3 Bit Load (E3)	1.85
4 Bit Load (E4)	1.46
5 Bit Load (E5)	1.12
Hard Sequence	
3 Bit Load (H3)	2.00
4 Bit Load (H4)	1.45
5 Bit Load (H5)	1.09

	F(1,216;1,288)
H1: H3>E3	5.47*
H2: E4>H4	.02
H3: E5=H5	.23
H4: E3>E4	8.69*
H5: E4>E5	7.62*
H6: E3>E5	16.25*
H7: H3>H4	12.02*
H8: H4>H5	8.09*
H9: H3>H5	20.11*

$^{*}p \leq .05$

Table 28

Tests on CHS Means for Three Target Loads

Target Load	Means(Hits/second)
3 Bit Load (L3)	1.93
4 Bit Load (L4)	1.46
5 Bit Load (L5)	1.11
	F(1,144)
H1: L3>L4	17.92*
H2: L3>L5	31.54*
H3: L4>L5	13.62*

*p< .05

Errors per second

Subject variables; Intelligence level and mental age.

Intelligence level, mental age, and instructions.

The analysis of variance on the errors per second dependent variable resulted in a significant intelligence x mental age x instructions interaction. As reported in Tables 29 and 30 , and illustrated in Figure 13, the results of the simple effects tests isolated the interaction to the speed instruction condition. At the younger mental age level, there were no significant differences in the number of errors per second obtained between the two intelligence groups; however, at the older mental age level, the non-retarded boys had many more errors per second than did their mentally retarded

Table 29

Simple Effects Tests for EPS Means Within the Significant Interaction of IQ, MA, and Instructions

Source	S.S.	d.f.	M.S.	F
IQ x MA x I	8.84	1,72	8.84	9.91*
IQ x MA at I_1	1.02	1,144	1.02	.65
IQ x MA at I_2	24.75	1,144	24.75	15.84*

*$p < .05$

counterparts. Furthermore, when comparing the mean number of errors per second within intelligence level, the older mental age boys of normal intelligence had significantly more errors per second than their younger counterparts whereas there were no differences between the two mental age groups of mentally retarded boys.

As seen in Table 31, the simple effects test results on the significant intelligence x mental age interaction were congruent with the findings on the intelligence x mental age x instructions interaction (_F_ (1,72) = 7.570, _p_ $< .01$). The older mental age non-retarded boys had more errors per second than their mentally retarded and younger mental age counterparts; there were no differences between the two mental age groups of mentally retarded boys. Clearly, this finding is due to the high number of errors per second under instructions for speed obtained by the non-retarded boys in the older age group.

Table 30

Tests on EPS Means for IQ and MA Groups

Under Instructions for Speed

Intelligence Level	Means (Errors/Second)
Retarded	
MA9 (R9)	.57
MA11 (R11)	.46
Non-retarded	
MA 9 (N9)	.46
MA11 (N11)	.93
	F (1,144)
H1: R9=R11	.81
H2:NN11>N9	14.79*
H3: N9=R9	.79
H4: N11>R11	14.85*

*$p \leq .05$

Mental age.

The above two interactions clarify the interpretation of the mental age main effect in which the older mental age boys obtained more errors per second than the younger mental age boys (F (1,72) = 5.123, $p \leq .05$); clearly this result is largely due to the high number of errors per second performed by the non-retarded boys in the older mental age group in the speed instruction condition.

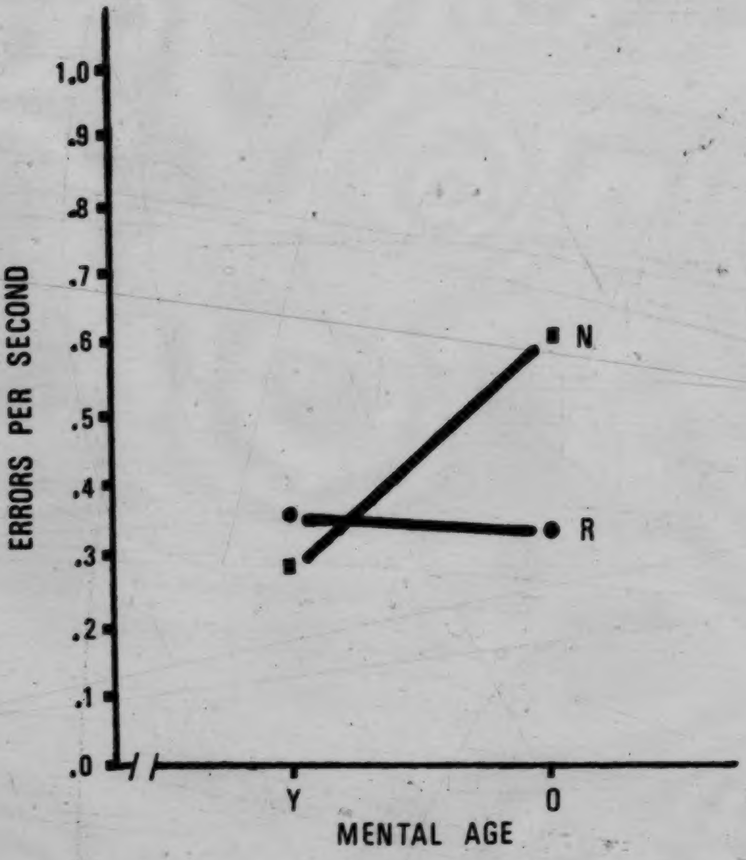

Figure 13. Mean EPS for IQ and MA Groups Under Instructions for Speed

Task variables: Target information load, testing sequence, and instructions.

Task information load, testing sequence, and instructions.

The target information x testing sequence x instruction conditions interaction was significant; as described in Table 32, the interaction was analysed initially on the basis of instruction conditions, the interaction was significant only under instructions for speed. Figure

Table 31

Tests on EPS Means for IQ Groups

at 2 Levels of MA

Intelligence Level	Means (Errors/second)
Retarded	
MA9 (R9)	.35
MA11 (R11)	.32
Non-retarded	
MA9 (N9)	.29
MA11 (N11)	.60

	F(1,144)
H1: R9=R11	.12
H2: N11>N9	12.58*
H3: N9=R9	.42
H4: N11>R11	10.49*

*$p \leq .05$

14 illustrates this interaction and the results of the simple effects test on it are presented in Table 33; the effect of the two testing sequences under instructions for speed are evident as the boys under the hard testing sequence, in which they met the easiest three bit target load last, had more errors per second on the three bit target load than the boys in the easy testing sequence who performed on the easiest target load first. The Tukey procedures comparing all

Table 32

Simple Effects Tests for EPS Means Within the Significant Interaction of Load, Testing Sequence, and Instructions

Source	S.S.	d.f.	M.S.	F
L x S x I	2.18	2,144	1.09	9.06*
L x S at I_1	.20	2,288	.10	.50
L x S at I_2	4.91	2,288	2.46	12.28*

$^*p \leq .05$

possible errors per second means resulted in significant differences between all three loads for the boys in the easy testing sequence; however, the boys in the hard testing sequence had significant differences in errors per second only between the three and five, and three and four bit target information loads.

Target information load and testing sequence.

The target information load x testing sequence interaction was significant (F (2,144) = 5.736, $p \leq .01$); as seen in Figure 15 and supported by the simple effect test results in Table 34, the interaction effect is similar to the results of the target information load x testing sequence x instructions interaction. The effect of including the accuracy instruction condition performance scores resulted in no significant differences in the number of errors per second between the two testing sequence groups at the three bit target loads. The effect

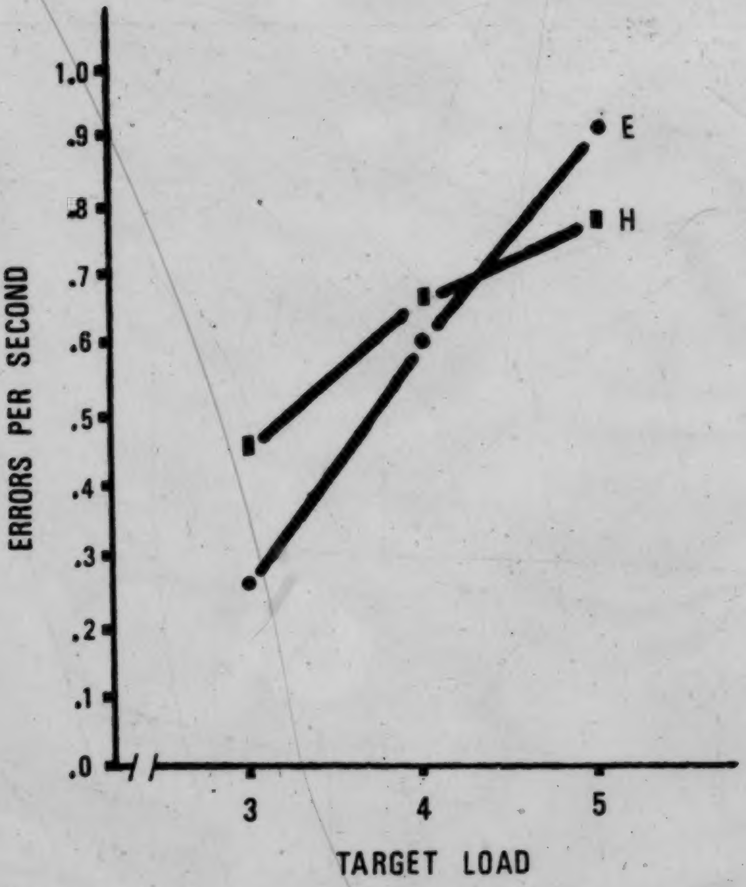

Figure 14. Mean EPS at 3 Target Loads Under 2 Testing Sequences with Instructions for Speed

of testing sequence on the target information load factor was exactly the same as in the three-way interaction; the easy testing sequence groups had significantly greater numbers of errors per second with each successive increase in target information load. These findings were true for the hard testing sequence groups as well, except for the comparison between the four and five bit target load means where no significant difference was found.

Table 33

Tests on EPS Means for Three Target Loads Under 2 Testing Sequences with Instructions for Speed

Testing Sequence	Means(Bits/second)
Easy Sequence	
3 Bit Load (E3)	.26
4 Bit Load (E4)	.59
5 Bit Load (E5)	.90
Hard Sequence	
3 Bit Load (H3)	.45
4 Bit Load (H4)	.67
5 Bit Load (H5)	.78

	F(1,216;1,288)
H1: H3>E3	8.32*
H2: H4=E4	1.34
H3: E5=H5	3.35
H4: E4>E3	6.33*
H5: E5>E4	5.84*
H6: E5>E3	12.17*
H7: H4>H3	4.10*
H8: H4=H5	1.98
H9: H5>H3	6.09*

*$p \leq .05$

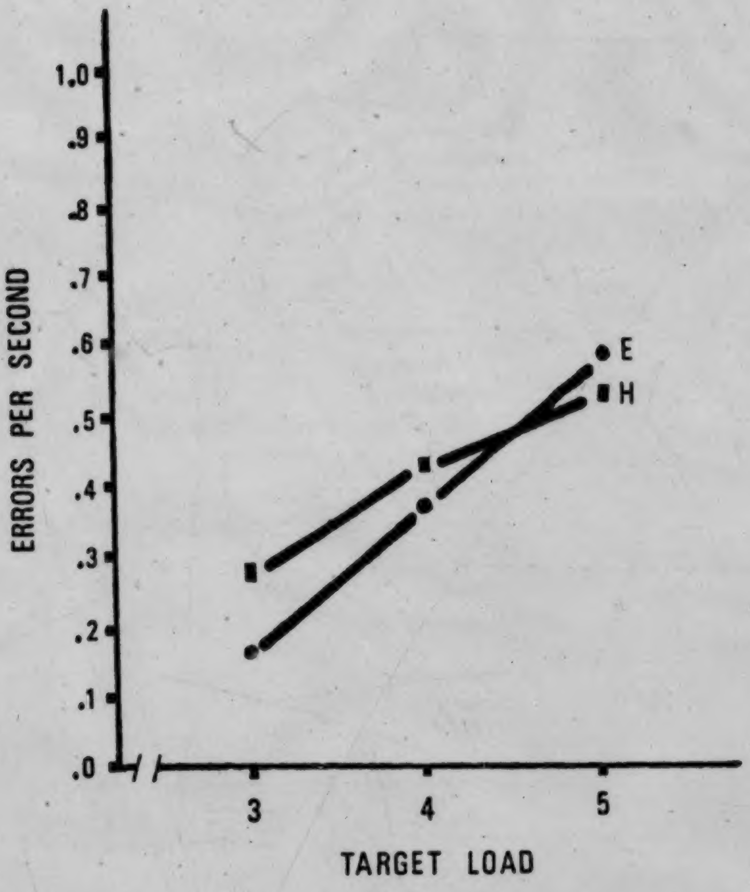

Figure 15. Mean EPS at 3 Target Loads
Under 2 Testing Sequences

Target information load and instructions.

The target information load x instructions interaction was highly significant (F (2,144) = 40.294, p < .01). As seen in Figure 16 and detailed in Table 35, the results of the simple effects test show that the boys executed more errors per second under instructions for speed at all three target information loads. Furthermore, the effect of target information load was different under the two instruction conditions; under instructions for speed there were more errors per second with each increase in target load whereas a significant difference under instructions for accuracy was found only between the three bit and five bit target loads.

Table 34

Tests on EPS Means for 3 Target Loads Under 2 Testing Sequences

Testing Sequences	Means(Errors/second)
Easy Sequence	
3 Bit Load (E3)	.16
4 Bit Load (E4)	.37
5 Bit Load (E5)	.58
Hard Sequence	
3 Bit Load (H3)	.27
4 Bit Load (H4)	.42
5 Bit Load (H5)	.51

	F(1,216;1,288)
H1: H3=E3	2.57
H2: H4=E4	.63
H3: E5=H5	.93
H4: E5>E3	11.15*
H5: E5>E4	5.67*
H6: E4>E3	5.48*
H7: H5>H3	6.47*
H8: H5=H4	2.47
H9: H4>H3	4.00*

*$p < .05$

Table 35

Tests on EPS Means for 3 Target Loads Under Instructions for Speed and Accuracy

Instructions	Means (Errors/second)
Accuracy	
3 Bit Load (A3)	.08
4 Bit Load (A4)	.16
5 Bit Load (A5)	.25
Speed	
3 Bit Load (S3)	.36
4 Bit Load (S4)	.63
5 Bit Load (S5)	.84
	F(1,216;1,288)
H1: S3>A3	40.88*
H2: S4>A4	119.64*
H3: S5>A5	181.69*
H4: A5>A3	5.56*
H5: A5=A4	3.07
H6: A4=A3	2.49
H7: S5>S3	15.29*
H8: S5>S4	6.56*
H9: S4>S3	8.73*

*$p \leq .05$

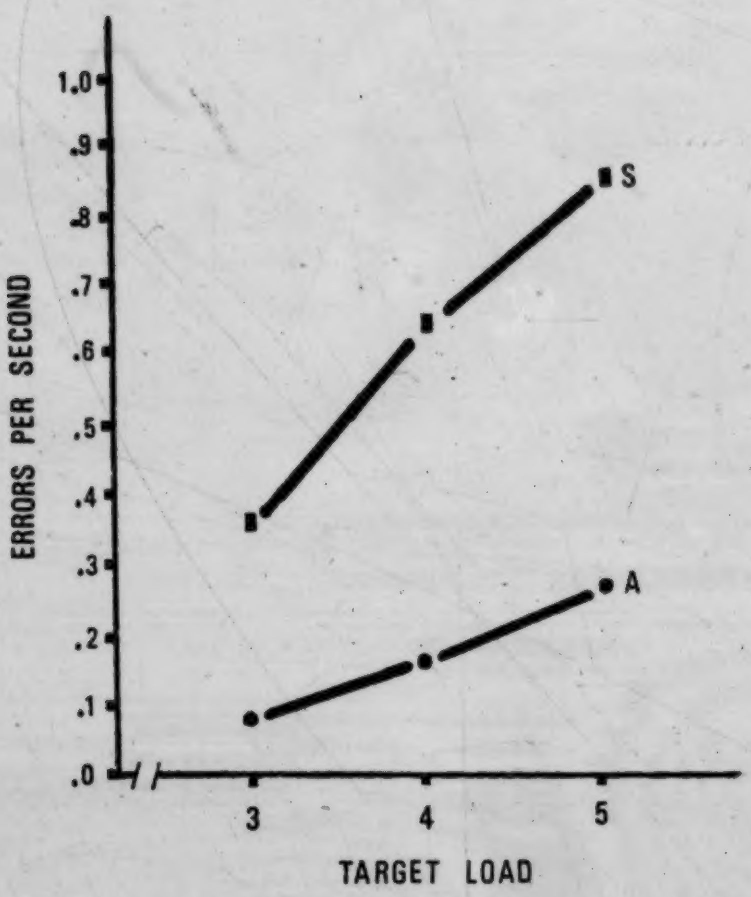

Figure 16. Mean EPS at 3 Target Loads Under Instructions for Accuracy and Speed

Target information load.

The above interactions must be considered when interpreting the highly significant target information load main effect (F (2,144) = 77.729, $p <$ .01); as described in Table 36, the Tukey procedures resulted in significant differences in mean errors per second with each successively more difficult increase in target information load.

Table 36

Tests on EPS Means for Three Target Loads

Target Load	Means (Errors/second)
3 Bit Load (L3)	.22
4 Bit Load (L4)	.39
5 Bit Load (L5)	.55
	F (1,144)
H1: L4>L3	6.72*
H2: L5>L3	12.48*
H3: L5>L4	5.72*

*$p < .05$

Trials.

The main effect for trials was significant (*F* (4, 288) = 10.607, $p < .01$). The results of the Tukey procedure between all possible comparisons of the errors per second means are presented in Table 37. The number of errors per second obtained by the boys on the first trial was significantly lower than those obtained on the other four trials; however, no other significant differences between trials were found.

Table 37

Tests on EPS Means for Five Trials

Trials	Means (Errors/second)
Trial 1 (T1)	.35
Trial 2 (T2)	.39
Trial 3 (T3)	.38
Trial 4 (T4)	.40
Trial 5 (T5)	.41

	F(1,72)
H1: T5>T1	7.88*
H2: T5=T2	3.01
H3: T5=T3	3.70
H4: T5=T4	1.52
H5: T4>T1	6.36*
H6: T4=T2	1.49
H7: T4=T3	2.18
H8: T3>T1	4.18*
H9: T3=T2	.69
H10:T2>T1	4.87*

*$p \le .05$

DISCUSSION

There are two basic sections included in the discussion of this study. The first section attempts to integrate the results from the four dependent variables, and discuss them, in relation to the subject and task variables in the study. The second section includes a more general discussion in which the findings are considered in terms of possible future research studies on the reciprocal tapping performance of mentally retarded persons.

1. Do the non-retarded boys exhibit better reciprocal tapping performance than their mental-age matched mentally retarded counterparts?

The non-retarded boys demonstrated superior reciprocal tapping performance in relation to their mental-age matched mentally retarded counterparts, at all three target information loads, under instructions for speed; however, under instructions for accuracy, this finding was true only at the older mental age level. The above finding is supported by the results on the primary dependent variable of rate of performance, and the supplementary measures of seconds per hit and number of correct hits per second.

The fact that the older non-retarded boys, under instructions for speed, had more errors per second over all target information loads than the three other subject groups reflects the sensitivity of this dependent variable to the dramatic decrease in mean movement time under instructions for speed obtained by the older non-retarded boys; however, the rate of performance results indicate that these boys, even though they performed at greater speeds and, therefore, with more errorful performances, were able to reciprocally tap more accurately and with less variability as measured by the more sensitive primary dependent variable.

The basic finding that the reciprocal tapping performance of the mentally retarded boys was inferior to the non-retarded boys under a variety of task conditions is congruent with recent comparative studies of fine motor performance (Knight, Atkinson & Hyman, 1967; Groden, 1969; Weaver & Ravaris, 1972; Simenson, 1973; Lally & Nettlebeck, 1977); and many earlier comparative studies (Bruninks, 1975). However, it is an especially significant finding because this study challenged directly the developmental lag hypothesis through the use of similar mental age levels within the two intelligence groups. This control procedure resulted in chronological age differences of approximately four and seven years between the younger and older mental age levels of the two intelligence groups. Therefore, the mentally retarded boys had definite advantages in terms of physiological maturation and past learning opportunities; even with these advantages, the mentally retarded boys had clear performance deficits in comparison to the non-retarded boys. On the basis of the above finding and past developmental studies of fine-motor performance, one may conclude with considerable confidence that an even greater performance deficit would have been found between the two intelligence groups if a chronological-age match design had been employed (Connolly, Brown & Bassett, 1968; Whiting & Cockerill, 1970; Fulton & Hubbard, 1974; Kerr, 1975; Surwillo, 1977).

The results of this comparative-descriptive study cannot identify the causes underlying the reciprocal tapping performance deficit, however, the results do provide some direction for future studies that might investigate the possible causal factors contributing to the poorer reciprocal tapping performance of the mentally retarded. Before suggesting possible future studies in this area, it might be profitable to consider the argument of traditional developmental-lag theorists that ascribes performance deficits in comparative studies to differences in motivation (Zigler, 1967).

A number of facts in this study suggest that differences in motivation are not of prime importance in explaining differences in reciprocal tapping performance between the two intelligence groups. First, observations of and discussions with each mentally retarded subject did not indicate that they found the task boring or difficult to understand. Only a few boys required a second explanation of the original instructions for the performance testing. All of the boys continued reciprocally tapping until the audio sound ended; in fact, a number of boys were keen to continue the testing at the end of the testing session. Second, if the motivation of the mentally retarded boys was less than the non-retarded boys during the testing sessions then this should have been reflected in differential performance decrements over the different target loads within the testing session; however, this was not the case. Therefore, one can argue that motivational factors should not be given high priority as an explanation of the performance differences.

2. Do the older mental age boys in each intelligence classification exhibit better reciprocal tapping performance than their younger mental age counterparts?

The two levels of mental age had different effects on the reciprocal tapping performance of the two intelligence groups. The mentally retarded boys had no differences in reciprocal tapping performance under all task conditions, as measured by the four dependent variables, that could be attributed to the two levels of mental age. In sharp contrast, the older non-retarded boys performed better than their younger counterparts on the rate of performance, seconds per hit and number of correct hits per second measures; however, due to their much faster mean movement time under instructions for speed, the older non-retarded boys obtained more errors per second than the younger boys. Even with these greater number of errors per second, under the speed condition, the older non-retarded boys obtained better rates of performance than their younger counterparts. The superior reciprocal tapping performance of the older mental age non-retarded boys is consistent with the findings of developmental studies on a variety of perceptual-motor tasks (Annett, 1970; Connolly, 1970; Whiting & Cocherill, 1974; Wickens, 1974; Fulton & Hubbard, 1975; Surwillo, 1977). Furthermore, the finding that they demonstrated superior reciprocal tapping performance under both instruction conditions is in partial agreement with some recent developmental studies of this task.

Connolly, Brown & Bassett (1968) compared the speed and accuracy of children aged six, eight, and ten on a reciprocal dotting task; they found a steady and significant increase in speed of performance, as measured by the number of dots during a trial, with increasing age, but found no similar increase in accuracy scores. These findings are in agreement with the present investigation on the seconds per hit dependent variable; however, the clear increases in rate of performance under both instruction conditions in favour of the older mental age non-retarded boys is in contrast to the findings in the above study. This inconsistency may be due to the differences in ages of the boys in the two studies, the boys in the present study were older; or, more plausibly, it is due to differences in the research designs. Connolly, Brown & Bassett did not use accuracy and speed instruction conditions. They reported clear increases in speed of performance as age increased but they also reported that the scatter distribution of pencil dots around the targets were different for the three age groups. Thus, speed of dotting performance was confounded with the accuracy of the performance as the older children who performed at significantly greater dotting speeds had scatter distributions that were spread along the direction of motion in flat oval shapes while the younger children created roughly circular distributions of dots around the centres of the target circles as they dotted at slower speeds. When these distributions were compared for accuracy no differences were found; however, if a more appropriate dependent variable such as the rate of performance had been used significant differences in favour of the older children might have been found. Unfortunately, the accuracy and speed components of the dotting task are confounded over the age groups tested.

Kerr (1975) in a serial tapping task measured the mean movement time of five, seven, and nine year old boys and girls under three levels of task difficulty. He found significant increases in speed of tapping performance with increasing age which is consistent with the findings of the present study. Unfortunately, Kerr used only an accuracy instruction condition and did not employ any other dependent variables to reflect the serial tapping performance of his subjects.

The finding of no significant differences in reciprocal tapping performance between the two levels of mental age for the mentally retarded boys may be partially explained by the chronological age of the subjects. Perhaps, reciprocal tapping performance does not improve dramatically during the post-adolescent years; more definitive conclusions must await further descriptive research on this question.

3. Do the levels within the task factors of target information load, testing sequence, and instruction conditions differentially effect the reciprocal tapping performance of the two intelligence groups at the different levels of mental age?

Intelligence level, target information load and instructions

The results of the four dependent variables indicate that the major task variables of target information load and instruction conditions did not differentially effect the two intelligence groups; furthermore, the significant intelligence level x target information load x instruction interactions for the supplementary dependent variables of seconds per hit and number of correct hits per second do not modify this general finding as they are isolated interactions which are unrelated.

Mental age, target information load, testing sequence, and instructions

The results of the analysis of variance on the mental age x target information load x testing sequence x instructions interaction within the rate of performance measure identified an isolated effect at the three bit target information load under instructions for accuracy in which the older mental age boys in the hard testing sequence groups had higher rates of performance than their younger counterparts. This effect is clearly due to testing sequence; the older mental age boys in the hard testing sequence group who performed on the most difficult target first, recognized after performing on the previous two more difficult target information loads that they could reciprocally tap on the easiest three bit target load at a much greater rate of performance than the younger mental age boys did after similar within-session performance experiences. This isolated mental age effect was not present within the analyses of the other three dependent variables; however, as discussed above, the significant target information load x testing sequence interaction present within the analysis of all four dependent variables, indicates that the above testing sequence effect was a consistent finding for all subject groups. The testing sequence effect is discussed in greater detail below.

Testing sequence

The two orders of testing sequence effected the reciprocal tapping performance of the boys in the hard and easy testing sequence groups under a number of different conditions. The basic testing sequence effect was evident at the easiest three bit target information load where the boys in the hard testing sequence groups obtained lower seconds per hit times, greater numbers of correct hits per second, and higher rates of performance than the boys in the easy testing sequence groups.

A plausible explanation for this basic testing sequence effect is that the boys in the hard testing sequence group, after performing on two successively easier target information loads, were able to utilize their experience within the testing session in order to increase their speed of performance and still maintain optimal accuracy tolerance limits when performing at the easiest target information load; whereas the boys in the easy testing sequence groups did not have the prior experience on more difficult target loads which would help them select more optimal tapping performance rates on the easiest three bit target load as they met this target load first. The reverse testing sequence effect in which one would expect those in the easy testing sequence groups to obtain superior performance scores at the five bit target load did not occur; this was probably due to the level of difficulty of the five bit target load which did not facilitate wide variations in speed of performance due to its more restrictive tolerance demands.

Further information on the effects of differences in testing sequence on reciprocal tapping performance comes from the higher order interactions within the rate of performance variable. The older mental age boys under the hard testing sequence obtained higher rates of performance than their counterparts in the easy testing sequence groups who had no within-session experience prior to performing on the easiest three bit target information load. The fact that the older mental age boys in both intelligence groups utilized this past experience more effectively than the younger mental age groups provides further support to the suggestion that within-session experiences facilitated increases in rate of performance under the hard testing sequence patterm.

An isolated instance of the effect of testing sequence operating in reversed order occurred within the target information load x testing sequence x mental age interaction located within the results of the mean movement time dependent variable. As indicated in Figure 9, the testing sequence effect was evident at the five bit target load in which the older mental age boys in the easy testing sequence group obtained lower seconds per hit times under both instruction conditions after performing on the previous two target loads, in contrast to the boys in the hard testing sequence group who performed on the most difficult target information load last. Again, the testing sequence effect was established only for the older mental age boys which was consistent with the finding discussed above.

Target information load and instructions

This was the first comparative-developmental study to include systematic changes in target information load and instruction. A number of interesting findings related to these two task variables were found.

The results from the seconds per hit, number of correct hits per second, and number of errors per second dependent variables indicate that at all three target information loads these performance scores were higher when the boys performed under instructions for speed. Furthermore, their performance improved at each successively easier target information load; with the exception of no difference in the number of errors per second between the three and four bit target loads under instructions for accuracy. It should be noted that the seconds per hit times of the boys in this study were much slower than those of the adults in Fitt's original study (1954). In fact, even though the adults in Fitt's study were reciprocally tapping with an emphasis on accuracy their times were faster, under all target loads, than the boys' times under instructions for speed.

The seconds per hit results indicate that the instruction conditions had a much greater effect on the boys than on the adults in Fitts and Peterson's study (1964). In fact, the seconds per hit time for the boys under instructions for speed at the five bit target information load was faster than their seconds per hit time under instructions for accuracy at the three bit target information load.

A recent adult study of reciprocal tapping performace in which the emphasis was on speed resulted in even lower seconds per hit times than in the Fitts and Peterson study (Flowers, 1974).

Flowers reported considerably more errors per second with the faster mean movement times which is congruent with the changes in instructional set in this study.

The relatively slow seconds per hit time under the accuracy instruction conditions had an interesting effect on the rate of performance results over the three target information loads. Under instructions for accuracy, there were no differences in the rate of performance; however, when the boys increased their seconds per hit times to faster levels more optimal rates of performance were obtained at the two easiest target loads resulting in significant differences between the two instruction conditions. As mentioned earlier, the boys increased their seconds per hit time under instructions for speed at the five bit target information load; but this increase over that used under instructions for accuracy, resulted in greater numbers of errors per second which depressed the rate of performance scores resulting in no differences between the two instruction conditions at the most difficult target information load.

Instructions

Reciprocal tapping performance improved under instructions for speed at each target information load as measured by the four dependent variables except for an isolated effect at the five bit target load. At this most difficult target load, the instructions for speed effect was present only within the seconds per hit time and errors per second dependent variables. The depressed results of the rate of performance and correct number of hits per second dependent variables resulted in no significant differences at the most difficult target information load; this was probably due to the fact that the boys selected an inappropriately fast movement time in relation to the small five bit information load. The faster movement times were counterbalanced by the greater number of errors per second and less correct hits per second resulting in less than optimal rates of performance under the speed instruction condition.

Trials

A slight practice effect was observed within the results of the seconds per hit dependent variable when comparisons were made between the early and late trials; however, these differences were not present between successive trial blocks. The results of the number of errors per second dependent variable reflect these findings to some extent; however, this practice effect was not sufficiently strong to effect the primary dependent variable of rate of performance and the supplementary dependent variable of the number of correct hits per second. Furthermore, no interaction involving the trial factor was observed indicating that the trial factor did not differentially effect the different subject groups.

GENERAL DISCUSSION AND FUTURE RESEARCH

This study was conducted from a theoretical framework based on human motor performance research. A number of human information processing models have been proposed to account for skilled perceptual-motor performance (Fitts & Posner, 1967; Adams, 1971; Welford, 1968; Schmidt, 1975). These models usually include descriptions of the following component processes that facilitate optimal perceptual-motor performance: sensory input, attentional processing, perceptual coding, decision-making, response selection, initiation, and execution, and the feedback systems associated with them. Furthermore, these models highlight the many interacting processes that underly perceptual-motor performance. The results of this study indicate that educable mentally boys do not reciprocally tap as well as their mental-age matched non-retarded counterparts which is congruent with past studies of the fine-motor performance of mentally retarded persons. However, in order to place future comparative research studies of reciprocal tapping performance in perspective, it is necessary to review selected research findings that indicate some of the deficiencies that the mentally retarded exhibit in important components of the human motor performance model. An understanding of these deficiencies has important implications for future comparative motor performance research.

Lally & Nettelbeck (1977) in a recent comparative study of choice reaction time used inspection time to measure the time required to detect and identify a stimulus signal. They demonstrated that the mentally retarded exhibit deficits in both the time required to detect and identify a signal (a perceptual factor) and the time required to make a simple gross movement that turned off the signal (a response factor). They argued that the perceptual factor of inspection time; i.e., the slower rate of sampling from the stimulus array, was the most relevant factor in terms of explaining the choice reaction time deficiencies of the mentally retarded.

Further evidence for a perceptual input deficiency in mentally retarded persons stems from comparative studies using visual masking tasks. The results of these studies indicate that in order to establish a satisfactory masking effect the interval times must be shorter for the non-retarded subjects (Spitz & Thor, 1968; Welsandt & Meyer, 1974). Furthermore, discrimination studies of numerosity and succession have shown that mentally retarded subjects require longer intervals to perceive the effects of these stimuli, thus providing more evidence of perceptual deficiency in the mentally retarded (Thor & Holder, 1969; Thor, 1973).

The mentally retarded have been found to be deficient in two different aspects of iconic memory. Iconic memory refers to the very short-term memory store that lasts several hundred milliseconds. It temporarily holds incoming stimulus information for initial processing before transferring it to short-term memory. Spitz (1973) has suggested that the icon of a mentally retarded person lasts longer than those of non-retarded individuals and this fact accounts for the slower rate of input of information in the mentally retarded. Furthermore, the recent comparative research results of Friedrick, Libkuman, Craig and Winn (1977) have confirmed earlier findings that have demonstrated slower read-out times from iconic memory by the mentally retarded

(Libkuman & Friedrich, 1972; Welsandt & Meyer, 1974).

Comparative studies of short-term memory function have identified a number of deficiencies in mentally retarded persons when cognitive-verbal stimulus material have been used. Belmont & Butterfield (1969, 1971), Ellis (1970), and Brown, Campione, Bray & Wilcox, (1973) have shown that the mentally retarded do not spontaneously rehearse in short-term memory tasks. Brown (1974) added a new dimension to comparative memory research by distinguishing between structural features and control processes. Using the original work of Atkinson & Shiffrin (1968), Brown noted that structural features are related to the physical system and have a fixed ceiling that is not amenable to training whereas control processes are aspects of the memory system that can be altered by training. The results of recent studies have indicated that the control processes associated with rehearsal strategies (Brown, Campione, Bray & Wilcox, 1973), and the intentional non-processing of irrelevant stimuli (Bray & Ferguson, 1976), in the mentally retarded respond to training indicating that they are, in fact, control processes rather than structural features of the memory system in the mentally retarded.

A number of other memory deficiencies have been identified in mentally retarded persons. At the present time, these deficiencies have not been classified as structural features or control processes; however, they do have relevance for understanding the perceptual-motor deficiencies of the mentally retarded. Dugas & Kellas (1974) have indicated that the rate of memory scan is inversely related to intelligence level. They used digits as stimuli and found that the non-retarded subjects scanned memory twice as fast as the educable mentally retarded subjects. Maisto

& Jerome (1977), using random forms for stimuli in order to equate the groups in terms of stimulus familiarity found that the educable mentally retarded adolescents in their study had both encoding and high-speed memory scanning deficits in comparison with non-retarded subjects. They attribute the relatively slow rate of memory scan to some permanent deficiency in central processing rather than a developmental deficiency.

Sugden (1977) has completed the first comparative study of visual motor short-term memory. Using a mental age match design, Sugden found that educable mentally retarded boys at mental ages six, nine, and twelve did not spontaneously rehearse the criterion distances in the linear positioning task during the rest conditions which was congruent with the results of cognitive-verbal short term memory studies that used the rest-interpolated activity recall paradigm. Sugden supplemented his recall data with a series of questions designed to examine the metamemory aspects of the task. The mentally retarded did not provide acceptable answers to these questions indicating that they were not using suitable mnemonic strategies during the rest period.

As indicated above, the mentally retarded are deficient in a number of component processes within the perceptual aspects of the human information processing model. Other than Sugden's (1977) recent study of visual motor short term memory few comparative motor performance research studies have used perceptual-motor tasks that have been primarily concerned with the response or motor aspects of the model (Bruininks, 1974; Wall, 1976). Lally and Nettlebeck (1977) in their comparative study of the choice reaction time of educable mentally retarded young adults have shown that the perceptual factor of inspection time was the main fact that accounted for the slower reaction times of the mentally retarded. They separated the response factor of movement time from the perceptual factor of inspection time within the task and reported that the simple movement times of the educable mentally retarded were clearly slower than those of the non-retarded young adults which is consistent with the results of the present study.

In summary, the mentally retarded are deficient in a number of component processes that underly perceptual-motor performance. At the present time, some of these deficiencies have been identified as control processes, i.e. they are amenable to improvement through training. In terms of ecological validity, the identification and remediation of these deficiencies is an extremely important comparative research objective. However, the complex interdependence between the various component processes that underly human motor performance emphasizes the need to specify clearly the task demands of comparative motor performance research tasks if a clear understanding of the motor performance deficiencies of the mentally retarded is to be attained. As indicated above, recent research findings have identified the important processes underlying reciprocal tapping performance; furthermore, the present findings indicate that the task meets the basic criteria for use as a comparative motor performance research task. Therefore, the continued use of the reciprocal tapping task in comparative motor performance studies seems justified. Some possible future studies are outlined below.

The first suggested study is based on the observation of Connolly, Brown, & Bassett (1968) that response strategy in the reciprocal tapping task changed with increases in age. They reported that their younger subjects reciprocally dotted in a manner best described as a series of discrete movements rather than as a continuous whole. This response strategy resulted in slower performance times and roughly circular distributions of dots around the targets. The older subjects tapped in a side to side motion at much greater speeds which resulted in flat oval shaped scatter distributions. McCracken (1973 cited in Wade, 1976) confirmed the observations of Connolly et al. (1968) by filming the tapping performance of six year old and ten year old children. The data indicated that the older children performed faster and in a more continuous fashion than the younger children.

The findings of the present study showed that in the speed instruction condition both mental age groups of non-retarded boys reciprocally tapped more proficiently than their mentally retarded counterparts. Why were there no performance differences at the younger mental age level between the two intelligence groups under instruction for accuracy? A plausible reason might be that at the age of eight years the non-retarded boys were using a less proficient response strategy in which they tapped in slower discrete movements rather than the faster more continuous movements used by their older non-retarded counterparts. It would be valuable to establish at what ages these changes in response strategy occur. A supplementary response strategy question stems from the finding that the older non-retarded boys under instructions for speed reciprocally tapped at dramatically more optimal rates of performance than the other three subject groups. They obtained these higher rates of performance by tapping at faster speeds and tolerating higher error rates. Why did the younger non-retarded boys and mentally retarded boys not employ similar strategies? The following suggested study might provide the answers to these questions.

A comparative-developmental study of reciprocal tapping performance should be conducted using only one target information load and using a set testing sequence. Samples of non-retarded and educable mentally retarded boys should be tested under instructions for accuracy and speed at at each age level from six to sixteen. Their tapping performance should be quantitatively measured using the four dependent variables employed in the present study. The qualitative changes should be analysed from unobtrusive video-tapes of the performances. Furthermore, structured interviews on what the boys were trying to do in terms of movement speed, error rates, and the optimizing of performance should be completed. The results of such a comparative-developmental study could replicate and extend the present findings and provide valuable information on the role of response strategies in reciprocal tapping performance.

A second study should be completed on the role of response strategies in reciprocal tapping performance differences between educable mentally retarded and non-retarded children. The research design for this study stems from the distinction made by Brown (1974) between control processes and structural features. Could the less proficient reciprocal tapping performance of the educable mentally retarded boys reflect deficiencies in response strategy that might be amenable to improvement through training? Control and training groups of mental-age matched non-retarded and educable mentally retarded boys should be randomly selected. The reciprocal tapping performance of the boys should be pre-tested at the three, four, and five bit target information loads with a fixed testing sequence under instructions for speed and accuracy. The boys in the experimental group should be given specific response strategy instructions related to optimal movement speeds and error rates. The groups should be retested to determine the effect of the response strategy training on their performances. The same dependent variables, video-tape techniques and interviews of the performers as outlined in the first study should be used to assess the effects of the response strategy training.

The final suggested study centers on the possible differences in corrective reaction time between educable mentally retarded and non-retarded boys. Beggs and Howorth (1968, 1972) demonstrated that an important limiting factor in aiming performance was the corrective reaction time of the performers. Are there differences in corrective reaction time based on intelligence level and chronological age? Educable mentally retarded and non-retarded boys at given mental age levels be tested under the vision-no vision paradigm using the measurement techniques recommended by Beggs and Howarth (1972). If differences in corrective reaction time are found, a response strategy training study such as the one outlined above should be completed to establish whether corrective reaction time is a structural feature or control process within reciprocal tapping performance. The information gathered from the above studies will certainly contribute to a better understanding of the response factors underlying the perceptual-motor performance of the educable mentally retarded.

REVIEW OF LITERATURE

The following selective review of the literature is divided into two major sections. The first section reviews comparative research studies on the gross-motor and fine-motor performance of persons who are mentally retarded. In response to some of the research difficulties that are identified in the first part of the review, criteria are established for the selection of comparative motor performance research tasks. The second section of the review focuses on the theoretical background and rationale for the use of reciprocal tapping as an appropriate comparative motor performance research task.

The Motor Performance of the Mentally Retarded

Many comparative studies have investigated motor performance differences between mentally retarded and non-retarded subjects. This selective review includes those studies that have used the Lincoln Oseretsky Motor Development Scale, gross-motor tests, and fine-motor tests as the comparative motor performance research task. Such a wide range of studies was included to demonstrate the need for new directions in this important research area.

A number of criteria must be considered when evaluating the results of comparative motor performance research studies. These include the level and variability of the subject groups with respect to intelligence, chronological age, mental age, behavioural history, and medical classification as well as whether or not the subjects were institutionalized. Other criteria are concerned with comparative task factors such as scoring procedures, reliability, testing protocol, and the purported purpose for using the particular task. Therefore, this review includes information on the subjects groups and comparative tasks and notes specific problems with them. At the end of this section of the review recommendations for future comparative motor performance research studies are provided.

Performance of the Mentally Retarded on the Lincoln - Oseretsky Motor Development Scale

Sloan (1951) compared 20 institutionalized retardates (CA males = 120, N = 10, IQ = 54.2; CA females = 118.7, N = 10, IQ = 56.2) and 20 normals (CA males = 120.1, N = 10, IQ = 105.8; CA females = 119.7, N = 10, IQ = 99.2) on the Lincoln - Oseretsky Motor Development Scale. Sloan obtained a quantitative score for each of six subtest areas by reducing all scores on the 65 test items into a simple pass or fail dichotomy and summing up all passes within each area. An analysis of variance resulted in significant differences between groups on all six subtests but no sex differences. He concluded that there is a significant relationship between intelligence and motor proficiency and that the mentally retarded are significantly inferior to children of average intelligence in motor proficiency.

Turnquist and Marzolf (1954) compared the performance of 11 institutionalized retardates (6 male, 5 female, CA = 13.6, IQ = 69) with 11 normals (6 male, 5 female, CA = 13.6, IQ = 102) on the Lincoln - Oseretsky Motor Development Scale. The authors analysed their results on an individual item basis and reported that on 20 items the average intelligence group performed significantly better while the retardates performed significantly better on five subtests. They concluded that educable mentally retarded adolescents have "deficiencies in motor ability when compared with those of average intelligence." (p.44)

Rabin (1957) investigated the effects of age, sex, and intelligence level on motor proficiency as measured by the Lincoln-Oseretsky Motor Development Scale. The research design included 5 age levels (10, 11, 12, 13, and 14 years), two intelligence ranges (40 - 54 and 55 - 69) and both sexes. Rabin reported no significant differences between the two levels of intelligence; however, he qualified this conclusion by noting that the examiners had used lower scoring standards when testing the low intelligence group thus confounding the results of this aspect of the study. The expected relationship between age and motor proficiency was significant; however, no sex differences were found.

Distefano, Ellis and Sloan (1958) investigated the proficiency of moderately mentally retarded adults on a variety of motor tests. Seventy-six institutionalized retardates (CA males = 19.3, N = 40, MA = 9.90; CA females = 22.25, N = 36, MA = 9.14) were administered the Lincoln - Oseretsky Motor Development Scale, the Heath Rail - Walking test, the Minnesota Rate of Manipulation Test, the Hand - Steadiness Test, and a grip strength test. Pearson product moment correlations between the above tests and chronological age were not significant. The intercorrelations matrices for each sex showed that the Lincoln - Oseretsky (.58 males, .40 females) and the Minnesota peg placing (.45 males, .41 females) and Minnesota peg turning (.37 males, .38 females) were the most highly related to mental age in each case. The authors suggested that task complexity is an important factor to consider in the relationship between mental age and motor performance, and concluded that there is a positive relationship between mental age and motor proficiency.

Malpass (1960) used the Lincoln - Oseretsky Motor Development Scale to compare the motor proficiency of three groups; institutionalized educable mentally retarded children (CA = 11.8, IQ = 62.8, N = 52), public school educable mentally retarded children (CA = 11.8, IQ = 67.8, N = 56), and a control group of non-retarded children (CA = 11.7, IQ = 110, N = 71). The Lincoln - Oseretsky scores did not differentiate between the institutionalized and public school retardates; but highly significant differences were found in favour of the normals in comparison to both retarded groups. Partial correlations indicated a significant relationship between intelligence and motor proficiency scores only for the retardates (r = .447, CA partialled out). Malpass suggested that it would be profitable to compare the above relationships if retardates and normals of the same mental age were employed.

In a more recent study, Hofmeister (1969) investigated the relationship between motor proficiency, as measured by the Lincoln - Oseretsky Motor Development Scale, and mental age. His subjects were special class educable mentally retarded children (CA = 12, MA = 8). The mental ages were calculated from the WISC full scale. The correlation of them with the total battery proficiency measure resulted in a moderately high product moment correlation (r = .514).

The results of the above comparative studies indicates that the motor proficiency of mentally retarded persons as measured by the Lincoln - Oseretsky Motor Development Scale is inferior to that of age-matched non-retarded subjects. This finding indicates that there may be significant motor performance differences between intelligence groups; however, a number of observations about the Lincoln-Oseretsky Motor Development Scale should be noted before accepting this conclusion. Oseretsky (1931) proposed that the six areas of his scale measured: general static coordination, dynamic manual coordination, general dynamic coordination, speed, simultaneous movement, and synkinesia. Vandenberg (1964) used the Pattern Hypothesis Varimax factor analytic technique in an attempt to verify Oseretsky's hypothesized factors. He reported that it was not possible to rotate the results of his factor analysis into even moderate agreement with Oseretsky's ideas about the underlying components measured by the Scale. On the basis of Vandenberg's study, the validity of the Scale is certainly open to question. An analysis of subtest results from comparative studies that used the Scale indicates that many of the subtests have scoring ranges that result in floor and ceiling effects which confound the interpretation of group motor performance differences. Therefore, the Lincoln - Oseretsky Motor Development Scale is of questionable value as a measure of motor performance in comparative research studies.

Gross-motor Performance of the Mentally Retarded

Fait and Kupferer (1956) tested 41 male retardates (IQ = 60.9, CA = 15.8) on the vertical jump test and the squat thrust test. The results of the mentally retarded on the vertical jump test compared favourable with normative data for normal secondary students; however, the retardates squat thrust results were considerable below the performance levels of the normals. The authors noted that the movement complexity in the squat thrust was much greater than that in the vertical jump. They reported that the retardates showed signs of stress and uneasiness only when performing the squat thrust task. They also found a partial correlation of .491 between intelligence level and squat thrust scores.

Howe (1959) compared the motor performance of non-retarded boys (CA = 6 - 12 years, IQ = 99.9) and non-retarded girls (CA = 6 - 12 years, IQ = 97.5) with educable mentally retarded boys (CA = 6 - 12 years, IQ = 67.5) and educable mentally retarded girls (CA = 6 - 12, IQ = 64.5) enrolled in special classes of a public day school. The groups were matched on chronological age, sex, and socioeconomic background. All subjects were administered each of eleven motor tests: Sargent jump, balancing on one foot, tracing speed, tapping speed, dotting speed, grip strength, zig-zag run, fifty yard dash, squat thrust, ball throw for accuracy, and paper and pencil maze tracing. The non-retarded boys were significantly better than the educable mentally retarded boys on all tasks. The non-retarded girls were significantly better than the educable mentally retarded girls on all items except for ball throwing and grip strength.

Francis and Rarick (1960) administered a battery of eleven motor performance tests to 284 mentally retarded children enrolled in special classes (CA = 7.5 - 14.5 years, IQ = 50 - 90). The tasks were purported to measure strength, power, agility and balance. The results indicated that while the mentally retarded children were poorer at every age level, the development of strength, balance and agility followed the same pattern as that of normal children. The same trend was noted for power tests (e.g., distance throw) although the degree of retardation was more marked. The authors concluded that retarded children are generally from two to four years behind published age norms for normal children.

Stein (1964) used the Youth Fitness Test to measure the motor performance of educable mentally retarded children who were enrolled in physical education classes. The test included seven tasks, usually administered over two days: first day, pull ups, standing broad jump, shuttle run, and sit ups; second day, fifty yard dash, softball throw for distance, and 600 yard run walk. Stein reported that the mentally retarded children in his classes either equalled or surpassed the national norm on every subtest. He attributed this unusual finding to "greater experience and opportunity for participation in physical activities and general familiarity with the test items." (p.208). The above conclusion provides encouragement for the possible benefits of physical education classes; but it should be recognized that it also emphasizes that the group tested were not typical of educable mentally retarded children.

Rarick, Widdop, and Broadhead (1967) conducted a major study to establish normative data on the Youth Fitness Test for educable mentally retarded children. A total of 4,235 mentally retarded boys and girls in the public schools of 21 different states were tested. The chronological age range of this large group was from 8 to 18 years. The results indicated that the retardates, at all age levels, were significantly inferior to national standards on all test items. The age and sex trends in performance on the tests followed those of intellectually normal children but the retarded children were two to four years behind normal performance standards; thus confirming the earlier findings of Francis and Rarick (1960).

Rarick and Dobbins (1972) conducted a major comparative motor performance study between educable mentally retarded boys and girls (CA = 6 - 13 years, IQ = 41 - 95, N = 261) and non-retarded children of the same age and sex (N = 145). The purpose of the investigation was to determine the factor structure of motor abilities underlying the two intelligence groups and to ascertain the extent to which chronological age and sex effected the factor structure. After considerable preliminary investigation, 47 test items were sufficiently reliable to use in the factor analysis. The basic components measured were: gross body coordination, limb-eye coordination, speed and coordination of gross limb movements, manual dexterity, kinesthesis, flexibility, static muscular strength, explosive muscular strength, muscular strength endurance, cardio respiratory endurance, body fat, and body size.

The results of the factor analysis indicated that the factor structures were very similar for the two intelligence groups when comparisons were made at specific sex and age levels. The educable mentally retarded had significantly greater body fat scores that the authors suggested indicated insufficient physical activity in comparison to the non-retarded subjects. The educable mentally retarded were considerably less proficient in motor performance tasks requiring gross and fine motor control, flexibility,balance, and muscular strength and power in comparison with the non-retarded of the same sex and age.

The above studies of gross-motor performance indicate that mentally retarded persons are less proficent than their non-retarded counterparts on a wide variety of gross-motor tests. The difference in performance becomes greater as intelligence level decreases. The next section of this review focusses on fine-motor comparative research studies.

Fine - motor Performance of the Mentally Retarded

Cantor and Stacey (1951) investigated the relationship between intelligence and manual dexterity. Male familial retardates (CA = 15.34, 14 - 18 range: IQ = 64.8, 42 - 82 range, N = 175) were administered 3 trials on the Purdue Pegboard Test. One trial scores for right, left and both hands were compared with the corresponding mean scores for 865 industrial men (from data reported by Tiffin and Asher, 1948); and three trial scores for the subtests were compared with the corresponding scores from 456 male veterans (from the data of Long and Hill, 1947). In both cases the non-retarded subjects performed significantly better than the retardates. In order to investigate the effect of intelligence on manual dexterity, the authors formed the following three IQ groups: IQ = 70 - 82, CA = 15.02, N = 52; IQ = 60 - 69, CA = 15.30, N = 80,; IQ = 42 - 59, CA = 15.79, N = 43, and reported the following results based on an analysis of variance of the data. On all tests the 70 - 82 IQ groups was significantly better than the 42 - 59 IQ group, the 60 - 69 IQ group was significantly better than the 42 - 59 IQ group, for all tests except both hands, one trial; however, no significant differences on any tests were found between the 70 - 82 IQ group and the 60 - 69 IQ group. The authors concluded that "one can generally expect to find marked inability to perform tasks involving manual dexterity in those whose IQ's are roughly below 60." (p.409). The authors also noted that there were no significant differences in performance among the age levels of retarded subjects. They suggested that mentally retarded males develop maximum manual dexterity skills before reaching the age of 14.

Reynolds and Stacey (1955) compared the six-pointed star mirror drawing performance of 108 retardates, arranged in three IQ groups, 50 - 59, 60 - 69, and 70 - 79, with 60 non-retarded subjects with an IQ range of 90 - 110. The average age of all groups was between 15 years and 15 years and 6 months. The results indicated that in almost all instances the non-retarded performed better than the retardates.$^{c}{}_{c}$c Furthermore, the time-on-target scores generally followed the IQ differentiation as far as group comparisons were concerned. Unfortunately, no significance levels for the above results were reported; however, a significant difference in group variances, increasing as group IQ decreased, was reported.

Ellis, Barnett, and Pryer (1957) used a mirror drawing task to study perceptual - motor learning in 170 moderately mentally retarded young men. The authors established three M.A. groups: MA = 4.8, CA = 16.0: MA = 6.7, CA = 17.1; MA = 9.5, CA = 18.0. The subjects performed ten massed trials of tracing a five-pointed double-lined star, while observing their hand movements in a mirror. The finding of Reynolds and Stacey (1955) relating performance time on the task with intelligence level was not supported; however, the tasks were not exactly similar. Furthermore, an analysis of the number of errors committed revealed clearly different performance curves for each of the three MA groups. A statistically significant inverse relationship between the total errors on the task and MA level was reported. The authors concluded that the degree of success on the task was directly related to MA level.

Ellis and Sloan (1957) investigated the relationship between mental age and rotary pursuit performance in mental retardates by dividing 88 male and female institutionalized retardates into the following three groups; MA = 3.6, CA = 15.6, N = 20; MA = 6.3, CA = 15.7, N = 49; MA = 9.4, CA = 18.4, N = 19. The pursuit rotor turntable rotated clockwise at 60 rpm. Scoring was total time-on-target per trial. Subjects were given 20 twenty second trials with twenty second intertrial rest periods. Using the mean time-on-target, the authors reported significant differences among the three MA groups in favour of the higher MA groups. The 20 trial performance curves for the three groups were clearly differentiated and subjects in the low MA group (MA = 3.6) did not improve whereas the two higher MA groups showed definite increases in proficiency. The product-moment correlation between MA and total time-on-target with CA partialled out was .43.

After reviewing the literature on the motor performance of mentally retarded persons, Annett (1958) employed a pegboard task to investigate the effects of increasing information load on the performance of retarded and non-retarded adults. The task demanded that subjects transfer, one by one, Braillet pegs which were standing upright in a board to a row of holes four inches away. The task was divided into four phases for analysis: reach, grasp, carry and assemble. The reach condition was varied with respect to information load. Black and white pegs were arranged in 4 conditions in order to increase the decision information load from 1 bit to 3 bits, i.e., selecting one peg from four required 2 bits of information to be processed and selecting one peg from eight possible pegs required three bits of information to be processed.

Seventy-two institutionalized male retardates were divided on the basis of verbal intelligence into three groups: High Grades with IQ's of 60 and over, Middle Grades with IQ's of 40 - 59, and Low Grades with IQ's of below 40. The 24 subjects in each group performed the task in all four conditions.

A counterbalanced design was used to equate presentation order and practice effects within the three groups. Annett qualified the use of analysis of variance by noting that the estimates of variance in the study were not strictly independent, since subject and learning effects and their interaction with each other and with the main effects were not surpressed. Nonetheless, the regression results did not differ significantly from linearity, but the slopes were significantly different. The differential effect of increases in information load on the decision times of the three groups was highly significant. The author noted that the channel capacity, in information theory terms, was severely limited in the lowest intelligence group. He suggested that this type of information might be useful in job classification efforts in sheltered workshops.

Baumeister, Hawkins and Holland, (1966) in a study designed to determine whether supplementary knowledge of results differentially affects the performance of non-retarded and educable mentally retarded adolescents on a pursuit rotor task. The subjects were 48 male institutionalized retardates (CA = 13.9, IQ = 79.3) and 48 male students obtained from the public schools (CA = 14.0, IQ = results not available.) Twenty pretest trials were given followed by rest periods of 0, 2, or 30 minutes. Ten additional post rest trials were also run. The analysis of variance indicated the normals to be significantly better on the pre-rest scores; however, a significant trials x intelligence groups interaction indicated that the initial superiority of the normals diminished with practice. Denny (1964) reported the same phenomenon occurred on other motor tasks. The addition of a buzzer as supplementary knowledge of results benefitted both retardates and normals, but not sufficiently to meet standard significance levels. Finally, the hypothesized facilitory effect, in favour of the retardates, of the supplementary knowledge of results was not supported. The authors suggested that the buzzer may not have been the most appropriate supplementary feedback to provide.

Knights, Atkinson and Hyman, (1967) compared the motor proficiency of 12 mongoloid retardates (CA = 14.2, MA = 3.5) and 12 non-mongoloid retardates (CA = 14.2, MA = 4.1) with normative data collected on normal children for the following six tests: 1. Maze Coordination Test: the dependent variables were the number of errors (touching the sides of the maze with the stylus), the amount of time the styluses touched the sides of the maze, and the total time per trial. 2. Hand-steadiness Test: the dependent variables were the number of holes and the amount of time the stylus rested against the side of the hole. 3. Dynaometer Test: six trials were administered to each hand and the average hand pressure was used in the analysis. 4. Grooved pegboard Test: the time taken to place ten grooved pegs into a small Layfayette pegboard was the score used in this test. 5. Simple Reaction Time: the score used in this test was the time required to press a telegraph key after the onset of a red signal light. The average of five trials was used. 6. Tapping Test: the mean number of taps for the three most rapid 10 second trials on the

Meyhan mechanical finger counter was used in the analysis.

The results of the analyses of variance for all six tests revealed no significant differences between the motor performance of the mongoloid and non-mongoloid retardates. Comparison of the performance of the retardates and normals indicated that the non-retarded were significantly superior on all the tests except the grip strength variable. The authors noted that "the retarded children performed these motor tasks at a level comparable to normal five year old children" (p.898). However, the grip strength results were comparable with the norms for 14 year old normal subjects.

Simenson (1973) compared the pursuit rotor performance of 100 special class retardates (CA = 149.11, IQ = 66.10) and 100 normal school children (CA = 148.45, IQ = 96.17) to investigate the effects of an immediate error signal on the acquisition and retention of pursuit rotor performance under the conditions of equal practice and learning to an equated mean level of performance. The authors reported that the learning of the task by normals was superior to that of the retardates and the immediate auditory feedback had no effect on performance. There was no significant difference in retention by normal and retarded subjects when each group had received an equal amount of practice and initial performance was held constant.

A recent study by Groden (1969) investigated the relationship between perceptual-motor behaviour as measured by grip strength, finger tapping speed, and key press, and level of intellectual functioning. Groden suggested that grip strength and finger tapping speed measured relatively simple motor abilities while the key press task which consisted of depressing four buttons on the corners of a five inch square as rapidly as possible tapped more complex perceptual-motor behaviour.

Fifty-four outpatient mentally retarded children (CA = 8.33, MA = 6.76) performed the key press and finger tapping tests for three 10 second trials and the grip strength test for three trials; the scores were the averages of the performances. Using partial correlation methods to control for chronological age, statistically significant correlations were found between mental age and key press (r = .871), finger tap)r = .830), and grip strength (r = .780). When both grip strength and chronological age were partialled out, the correlations between key press and mental age remained high and significant (r = .563). The corresponding second-order partial correlation with finger tapping and chronological age removed was also significant (r = .487). Groden concluded that the above findings supported "the probability that behaviour on the motor proficiency test, key press, is a further manifestation of the adaptive deficiencies of these children over and above any associated simple motor problems as these might be reflected in grip strength and finger tapping (p.375).

Weaver and Ravaris (1972) compared the psychomotor performance of mentally retarded subjects and psychiatric patients. They also investigated the relationship between the psychomotor test scores and the degree of retardation in the institutionalized retardates. The mentally retarded adults were divided into 3groups in which 78 were classified as mildly retarded (IQ = 52 - 67), 180 as moderately retarded (IQ = 36 - 51), and 14 as severly retarded (IQ = 20 - 35).

The psychomotor test battery administered to the retardates consisted of the following tests: 1. Reaction time: removal of forefinger from telegraph key in response to a buzzer. 2. Tapping: the rate of tapping on a telegraph key for five seconds. 3. Serial reaction time: self-paced tapping with a wand on target discs as indicated by stimulus lamps. 4. Transport-assembly test: basically a Purdue Grooved Pegboard which was modified so that the pegs had to be rotated after insertion. The times to grasp and place pegs, and to transport the pegs in both directions, were measured separately.

Comparisons between the results obtained from the retardates with data collected previously on psychiatric patients (Weaver & Brooks, 1967), indicated that the retardates were significantly inferior in performance on all of the above tests. Furthermore, the test battery clearly differentiated, using multivariate analysis, the poorer motor performance of the moderately retarded group in comparison with the mildly retarded.

The above studies reviewing retardate performance on a wide variety of fine-motor tasks indicate that the mentally retarded were inferior to their non-retarded counterparts in almost all instances. Furthermore, the degree of fine-motor deficiency was related to the level of intelligence of the subjects involved. Motor deficiency being especially severe in those retardates with intelligence test scores that were less than sixty. Correlational studies between mental age and fine-motor proficiency also resulted in moderate positive relationships.

The one study (Annett, 1958) that varied the decision load within a task resulted in differential effects on the lower retardate groups.

Groden's finding (1969) that the task difficulty of fine-motor tasks was an important factor in the degree of relationship between mental age and fine-motor proficiency, underlines the need for comparative studies which vary the task demands of the motor performance task. Unfortunately, no studies of retardate fine-motor performance have systematically varied task difficulty.

The next section of this review provides the theoretical rationale for the use of a reciprocal tapping task as an appropriate measure of fine-motor performance in comparative research studies.

TASK CONSIDERATIONS

Fitts' Law

Fitts (1954), in a classic paper, used information theory concepts in an attempt to measure the information capacity of the human motor system. He defined the motor system "as including the visual and proprioceptive feedback loops that permit S to monitor his own activity" (p.381). He postulated that the information capacity of the motor system could be measured by its ability to produce consistently one class of movements from among several alternative movement classes; furthermore, he argued that the

> information capacity is limited only by the amount of statistical variability, or noise, that is characteristic of repeated efforts to produce the same response. The information capacity of the motor system, therefore, can be inferred from measures of the variability of successive responses that S attempts to make uniform. (Fitts, 1954, p.381-382)

Fitts also proposed that there was a fixed information-transmission capacity of the motor system and that this fact permitted the development of an equation to express quantitatively the relationship between the amplitude, duration, and variability of motor responses. He postulated that if repetitive movements of a fixed average amplitude were speeded up, then on the average each movement could provide less information, resulting in a specifiable increase in movement variability. Furthermore, if the movement amplitude was increased then movement variability and/or average duration would be increased.

Three interrelated equations resulted from Fitts' formulations. The first proposed that movement time could be predicted by : Movement time $= a + b \log_2 \cdot (2A/W)$ where A is the amplitude of the movement (the distance from the center of one target to the center of the other), and W is the width of the target within which the movement is required to end, measured parallel to the direction of the movement. As Welford (1968) has noted, the essential point of this relationship is that it makes movement time constant for any given ratio between amplitude and target width.

Fitts recognized that using 2A rather than A in the formulation was arbitrary; but he argued that it ensured that the logarithm would always be positive, as well as reflecting the fact that the subject was choosing a specific movement which had the possibility of either over - or undershooting the target. He also mentioned that it would not always be accurate to use W as the measure of movement variability, as the subject might concentrate his shots in a narrower range than the target width, therefore one would expect a greater movement time in such an instance.

The second equation specified the information content of a movement and was given by:

$$\text{Index of difficulty} = \log_2 (2A/W)$$

where the parameters in the equation were those outlined above. The final formulation, that Fitts proposed was the prediction of the rate of information transmission which was defined as:

Rate of information transmitted = ID/MT,

where ID is equal to the index of difficulty, and MT is equal to movement time.

Fitts (1954) developed the above formulations in conjunction with three experiments in which he attempted to verify empirically the relationship between amplitude, movement variability and movement time. The tasks were to tap alternately two plates separated by four different distances, transfer washers from one pin to amother, and transfer pins from one hole to another. Only the first experiment which involved reciprocal tapping will be described here. In this experiment the subject was required to hit alternately on two metal strips, six inches long, using a metal-tipped stylus. The long axes of the strips were perpendicular to the line of movement between them. Four widths of target strip were used: 2, 1, .5, and .25 inches at each of four distances between centres; 2, 4, 8, and 16 inches. Fitts reported that for each category of target width, movement time increased progressively as movement amplitude increased. Likewise, for each amplitude, movement time increased progressively as tolerance was decreased. The average movement time plotted against the index of difficulty resulted in an almost linear fit to the data.

Fitts also postulated that the rate of information transmission (define as C = ID/MT) should be constant over a wide range of movement amplitudes and tolerances. He found that the rate of performance varied between 10.3 and 11.5 bits per second over eight different index of difficulty conditions; only in the least exacting condition studied

(A = 2 inches, W = 2 inches) did the performance rate markedly fall off. He concluded that:

> the fixed information - handling capacity of the motor system probably reflects a fixed capacity of central mechanisms for monitoring the results of the ongoing motor activity while at the same time maintaining the necessary degree of organization with respect to the magnitude and timing of successive movements. (Fitts, 1954, p.391).

Welford's Additions to Fitts' Law

Welford (1968) has suggested three unsatisfactory aspects of Fitts' original formulations; following Crossman (1957) he suggested that in order to prevent the constant A from becoming negative, as it was in Fitts' (1954) plotting of average movement time against the index of difficulty, that the amplitude should not be multiplied by 2.

Welford (1968) proposed a second modification in which a constant of ½ W was added to the amplitude in the numerator of the equations. The rationale for this modification was based on the argument that the subject is called upon to choose a distance W out of a total distance extending from his starting point to the far edge of the target. This correction also ensures "that the logarithm can never be a negative, since in the extreme case when the movement begins at the edge of the target A = ½ W" (p.147).

Welford's final suggestion centered on the amount of target used in the aiming tasks; he found that subjects dotting between with a pencil used different amounts of the target areas. When the targets were wide and the distance short, the subjects used very much less than the full target width; therefore, the amount of information transmitted was much greater than Fitts' equation predicted because the effective target width (W) was narrower. Therefore, Welford (1968), following

Crossman (1957), suggested the following correction to account for the amount of effective target width used by subjects. The correction was based on the fact that the information in a normal distribution is $\log_2 \sigma\sqrt{(2\pi e)}$ where σ is the standard deviation of the distribution. Since $\sqrt{(2\pi e} = 4.133$ and a range of ± half this, i.e. 2.062σ, includes about 96 per cent of a normal distribution, then if about 4 per cent of shots fell outside the target, $\log_2 W$ would be an accurate estimate of the information contained in the distribution of shots. Furthermore, if the errors exceed 4 per cent the effective target width is greater than W, and if the errors are less than 4 per cent the effective target width is less than W. The exact effective width can be calculated from tables of the normal distribution.

Welford (1960) summarized the above three corrections in a modification of one of Fitts' original equations:

Movement time $= K \log \left(\frac{A^1}{W^1} + .5 \right)$ where W^1 is the mean width of the two distributions of hits, one at each end, observed with any particular combination of A and W and A^1 is the distance between the centres of these distributions.

Knight and Dagnall (1967) used a task in which the subjects aligned a pointer with each of two targets alternately. The targets had 6 inch long (radial) sides and four target widths were used, 0.25, 0.5, 1, and 2 inches in combination with four amplitudes (angular separation) 2.5, 4, 8, and 16 inches, the measurements were taken around the circumference of the disc. Fitts' (1954),Crossman's (1957) and Welford's equations were used to calculate the index of difficulty, and movement time was plotted against the three indices of difficulty.

Regression techniques were used to decide which index of difficulty provided the best fit of the experimental data. Welford's suggestion of $\log_2 (A/W) + .5$ gave the best fit to the experimental time data.

Fitts and Peterson (1964), using a discrete tapping task, investigated the effects of response amplitude and terminal accuracy on 2 choice reaction time and on movement time. The subjects had to move a stylus a variable distance in the direction indicated by a signal light. The response had to be terminated on target plates of different sizes. The amplitudes of 3, 6, and 12 inches and target widths of 1, .5, .25, and .125 were used. The two independent variables were the index of difficulty and the number of directions condition. The subject did not know whether to move left or right until the signal light came on; then he moved as rapidly as possible to the target plate indicated by the light. Reaction time and movement time were the dependent variables in the study.

The results of the experiment indicated that increases in the index of difficulty have large and systematic effects on movement time whereas they have a relatively small effect on reaction time. These findings provide considerable support for the contention that reaction time reflects the uncertainty of a subject with regard to which one of a set of movements should occur while movement time reflects the relative accuracy of termination required by the movement.

The rate of information transmission or rate of performance varied from 22 bits per second for an index of difficulty of 2.5 (the least difficult movement studies), to 14 bits per second for the most difficult movement studied with an index of difficulty of 7.5 Fitts and peterson (1964) suggested "that the motor system is relatively more efficient in producing low-information responses" for discrete movement responses (p117). The rate of performance in this discrete tapping task was faster (between 14 and 22 bits per second) than the rate of transmission of approximately 10 bits per second in Fitts' (1954) original serial tapping task; however, the higher rate of performance was partly due to the fact that time on target was not included in the total movement time.

It should be noted that the index of difficulty in this experiment was calculated by both Fitts' original equation to predict movement time as well as by Welford's (1960) correction of it; the latter method provided the best fit of the data.

The effect of instructional sets for speed and accuracy in movement tasks of varying degrees of difficulty was investigated by Fitts and Radford (1966). The subjects were given monetary bonuses in accordance with a set payoff matrix which emphasized speed, accuracy or neutrality of instruction set. Increasing the speed payoff condition resulted in decreased movement times; but the number of errors also increased under this payoff condition.

Fitts and Radford also investigated whether the increase in errors balanced the increase in speed so that the rate of information transmission would be constant under the three instruction conditions. Using Welford's (1960) method to calculate effective target width, the authors calculated the target widths which would be necessary at each speed for 95 per cent of the movements to hit the target (hits were assumed to be normally distributed about the center of the target). The rate of transmission was then solved by substituting the effective target width (W^1) for the actual target width (W). Small but consistent increases in the rate of performance were found in the speeded condition in comparison with the accuracy condition; however, it should be noted, that shifting from a speed to accuracy instruction set had less effect on movement time than did a one-bit change in the index of difficulty.

Welford, Norris, and Shock (1969), in a detailed study of how movement accuracy changes with increases in age, employed an aiming task in which movement times were recorded for dotting from side to side with a pencil between two targets drawn on paper. The use of paper and pencil permitted the location of each shot to be recorded. Serial dotting runs of fifty shots in each direction with all combinations of $(A \# \frac{1}{2} W) = 50, 142, 402$ millimetres and $W = 32, 11$, and 4 millimetres were completed.

The preliminary results indicated that the distribution of shots were not exactly normal but were between normal and rectangular; therefore, the width of the distribution of shots for each subject was taken as the distance between the extreme shots excluding any wild deviations.

The authors plotted the index of difficulty against the time per movement expecting to find that Welford's (1960) equation of: Movement time $= K \log (\frac{A1}{W1} + .5)$ would provide a perfectly linear fit of the data. The results were as expected for the larger target widths but the movement times for the narrower target were too high.

In attempting to find an explanation for the above phenomenon, the authors reported that when the points relating movement time to the index of difficulty were plotted for any one target width at different amplitudes of movement and then joined, the resulting slope had a value of about 10 bits per second; furthermore, when the points for any one amplitude at different target widths were joined the resulting slope was about 6 bits per second. Based on the above observations the authors suggested that perhaps two distinct control processes were operative; "a faster distance-covering phase and a slower phase of 'homing' on to the target" (p.10).

The above finding prompted Welford and his associates to postualate a new prediction equation for movement time which would account for two different slope constants for amplitudes and targets respectively. The resulting equation was:

Movement time = $a \log A^1 - b \log W^1_1 + (b - a) \log W^1_o$ where W^1_o is the scatter of shots that would be observed with ballistic movements of amplitude A^1_1 and W^1_1 is the scatter observed with any particular target width under consideration.

The authors plotted their data using the above equation and all the points fell close to a striaght line. The rate of gain of information in bits per second implied by the slope constants a and b were 9.65 and 5.65 respectively. These figures are close to those reported by Fitts (1954) for the rate of performance on his reciprocal tapping task and the 5.65 bits per second is close to Hick's finding for choice-reaction times. The authors conclude that "it is tempting to suppose that while the former represents some capacity of motor mechanism, the latter is limited by the same elements of the sensory-motor chain as choice-reactions" (p.12).

Robinson and Leifer (1967) used a reciprocal tapping task in which the targets were drawn on white paper and a pencil was used as the tapping instrument. The subjects moved the pencil back and forth between the targets for 15 seconds. Twelve experimental conditions consisting of all combinations of three amplitudes, A = 3, 6, or 12 inches, and four target width, W = 1.5, .25, or .125 were administered. The investigators asked the questions: "First, does the channel capacity remain constant over widely differing error rates; and second, how accurately can S perform an error-time tradeoff following simple, verbal instructions" (p.901).

The first group was instructed to keep their error-rates (per cent of pencil marks outside the targets) as low as possible without unduly slowing their movements; an error rate of one to two per cent was suggested. The second group was told that a substantial error-rate would be permitted in order to increase the movement speed; an error rate of ten to fifteen per cent was suggested.

The results indicated that the first group's error rate was approximately 3 per cent while that for the second group was 19 per cent; however, the striking finding was that the information transmission rate (bits per second) for the two instruction condition groups were essentially the same.

Bainbridge and Sanders (1972) have recently tested Welford's (1969) contention that the logarithmic transform provides additivity of amplitude and accuracy effects. Using the same type of paper and pencil dotting task as Welford (1969) the subjects in this study made dotting movements in time to a metronome set at speeds of .6, .4, and .3 seconds per movement. Three amplitudes were used, 4, 8, and 16 inches. Thus amplitude and duration of movement were controlled while the resulting accuracy of the movements were measured by the method that Welford (1969) had employed.

The fundamental question of the study centered on whether the data was best fitted by Fitts' original equation in which movement time is a logarithmic function of the ratio of the amplitude and accuracy of the movement whatever their absolute sizes; or by Welford's (1969) equation in which the logarithmic transform results in A^1 and W^1 being independent and additive. The data was plotted using both equations and the results supported Fitts' ratio formulation rather than Welford's recent proposal.

The above studies have indicated that Fitts' Law, with minor corrections, accurately describes the relationship between movement time, target width, and amplitude in aiming tasks. Recent research efforts have attempted to delineate what processes underly such basic movement aiming tasks; the central finding has been the increasing importance of the role of visual feedback as target width decreased in the tasks.

Visual Feedback and Reciprocal Tapping

Woodworth (1899), in a pioneering paper, addressed the question of how long it takes to process visual feedback. He asked subjects to make back and forth movements with the eyes either open or closed; the subjects were then asked to reproduce the length of the previous movement. Different stroke rates were employed in the experiment and Woodworth found that at a rate of 100 to 180 strokes per minute the accuracy of the movement was no better with the eyes open than with the eyes closed.

Vince (1948), in a similar study, asked subjects to move to a fixed line and back with the eyes either open or shut. He reported results similar to Woodworth suggesting that the time required to process visual feedback was about 500 milliseconds. This finding makes a visual feedback explanation of Fitts' Law untenable as many of the movement times he obtained were less than the 500 millisecond figure. However, Keele (1968) has pointed out that the method Woodworth and Vince employed overestimated the visual feedback processing time in tat some time was spent in reversing the back and forth movements.

Keele and Posner (1968) investigated the time required to process visual feedback in a study in which subjects had to move a stylus a distance of 6 inches to a one-quarter inch target. The subjects completed the task with the lights on and in the dark. The results indicated that movements of approximately 190 milliseconds were performed with equal accuracy whether the lights were on or not. Movements of 260 milliseconds, or slower, were more accurate when the lights remained on. The authors concluded that it takes approximately 190 to 260 milliseconds for visual feedback to be useful for movement correction.

The above finding lends support to the notion that precise movements consist of a series of movements corrected by visual feedback processing. Keele (1973) has suggested that movement control consists of a series of decisions in which the signal requiring a response is the discrepancy between the predicted termination point of the moving limb and the position of the target; the response to the discrepancy is the movement correction. Posner and Keele (1969 cited in Keele, 1973) expanded the above position to postulate that if movements involve a series of decisions then they should also require attention. A series of studies have been completed to investigate this notion.

Posner and his associates have used a probe stimulus technique to measure the attention demands of specific tasks. An important assumption of this technique is that the investigated task is being performed at optimal efficiency; control for this assumption is obtained by comparing task performance with and without the probe stimulus intervention. The probe stimulus may be introduced during any given aspect of a task and the differential delays in reaction time are considered to be representative of the attention demands of the task under study (Posner and Boies, 1971).

Posner (cited in Keele, 1973) had subjects align a pointer with either a narrow or wide target by turning a knob. A noise probe stimulus signal was employed and subjects responded to it by pressing a key with the free hand. The attention demands of the tasks were a measured by the reaction time to the probe signal. Another condition in which no movement was required except a response to the probe signal provided the necessary control comparisons. When compared to the control the experimental reaction time increased at all points probed during the movement particularly as the target was approached. Furthermore, the probe reaction time was always greater during movement to the narrow target than during movement to the wider target.

Ells (1973) used the probe technique to investigate attention demands during the decision period preceding a movement and during the actual performance of a movement. Ells varied directional uncertainty, by using a directional signal lamp in his display, and movement precision by having subjects align a pointer with a narrow 1.3 centimeter target width or a wider target of 7.6 centimeters. He introduced a probe signal at various points following the directional signal designating the movement target and at various points during the actual movement.

Ells found that the relative degree of attention as measured by the probe reaction times increased from no attention at all when the movement was terminated by a stop to increasingly greater times as the targets became narrower. He concluded that the more precise the movement the more attention was required. Ells also reported that the attention demand during the decision period did not depend on the difficulty of the ensueing movement; thus providing further support for the contention that the selection and execution of a particular movement are performed by relatively independent processes.

Beggs and Howarth (1970) attempted to show the intermittent nature of visual feedback in a simple speed and accuracy experiment by interrupting the visual feedback loop. Subjects were required to aim with a pencil at a vertical line target about two feet in front of their faces from a home position near their shoulders. The root mean square of the distribution of pencil marks about the target was used to reflect the accuracy of movement. The movement speed was varied by having the subjects make repeated movements in time with a metronome. The illumination of the room was controlled by an infrared beam which automatically extinquished the lights in the room when it was interrupted by the pencil. The infrared beam was moved to various distances from the target in order to vary the amount of visual feedback time available for a given movement.

The authors reported that removing visual feedback when the hand is close to the target has very little effect on the terminal accuracy provided that there is less than one corrective reaction time, found to be approximately 290 milliseconds, between the removal of the feedback and the hand reaching the target. At greater times and distances away from the target the removal of visual feedback has an effect on terminal accuracy which depends mainly on the distance the hand moves in the dark.

Howarth, Beggs, and Bowden (1971) extended the above work on the intermittent nature of visual feedback by developing rational equations to describe and explain the relationship between speed and accuracy of movement. They postulated that if they could determine the precise relationship between distance and time as a hand approached a given target, then the distance the hand is away from the target at one corrective reaction time to impact could be calculated. Furthermore, they argued that if the hand travelled in an uncontrolled manner over the distance in which no corrective movements could be made then there should be a simple relationship between the length of the uncontrolled part of the movement and terminal error.

The apparatus employed in this study was the same as in the above study by Beggs and Howarth (1970). One trial for each subject consisted of 30 movements towards the target at a given speed while being timed over a given distance from the target. Each subject performed at six speeds: 42, 60, 84, 100, 125, and 144 beats per minute of a metronome; with 10 trials of 30 movements for each speed. The error of aiming was measured by the root mean square of the distance of the pencil marks from the target line.

The authors used the Beggs and Howarth (1970) estimate of one corrective reaction time being equal to 290 milliseconds in order to calculate d_u, the length of the uncontrolled terminal segment of the movement. The relationship between mean square error scores (E^2) and d_u^2 at each speed was then plotted. The resulting best fitting straight line accounted for 98.68 per cent of the variance and was reported as $E^2 = 5.87 + 0.000106\ d_u^2$. The authors attributed the first source of error to tremor of the hand and arm and the second source of error to the distance to impact at which the last corrective movement was made.

Using the above equation the authors predicted the effect of movement speed on accuracy by plotting the relationship between mean square error scores and the predicted relationship at different movement speeds. The predicted line was linear and provided an extremely close fit to the data. The authors concluded that the accuracy of movements made in the dark to a previously seen target is a function purely of their length, and not the speed at which the movement is made. Furthermore, the results support the notion that error on target is linearly related to the distance through which the hand moved without corrective feedback.

Megaw (1975) performed a series of experiments to examine some of the parameters underlying Fitts' tapping task. The major thrust of his research centered on the differences between serial and discrete tapping performance. Megaw found that in serial tasks movement time was determined not only by the accuracy demands of the movement but also the attention given to the processing of feedback derived from the preceding movement, particularly the feedback related to end-point accuracy. He noted that his findings were consistent with the recent work of Beggs and Howarth (1972) and the earlier work of Fitts and Posner (1968).

Kantowitz and his associates have studied reciprocal tapping performance in terms of the central processing demands the task makes when performed as an interpolated task in the Brown-Peterson short term memory research paradigm. They concluded that reciprocal tapping was a highly response loaded task as it had little effect as a distractor to rehearsal in verbal short term memory studies (Kantowitz & Knight, 1976; Roedinger, Knight & Kantowitz, 1977).

The above section presented a review of studies based on Fitts' Law (1954) relating movement time to movement variability and amplitude. A number of modifications to the original relationship were reported and a wide variety of studies supporting its general applicability were presented. Recent studies centering on the importance of corrective movements based on visual feedback were discussed.

In conclusion, reciprocal tapping is an excellent fine-motor task to use in comparative research investigations as it permits the manipulation of target information load under a number of instruction conditions. The dependent variables used to measure reciprocal tapping performance minimize floor and ceiling effects which facilitates the interpretation of possible interactions between subject and task variables. Furthermore, if significant differences in reciprocal tapping performance are found between non-retarded and retarded subjects then a comparative investigation of the visual feedback processes underlying reciprocal tapping performance could be initiated.

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APPENDIX A

General instructions prior to instruction condition instructions:

This is a machine that sees how fast you can hit these targets. You have to hit the targets one after another with this tapper. When this light goes on put the tapper on this target and get ready to start tapping. This sound (tone pressed for subjects to hear) will go on when you should start tapping the targets. Keep tapping until the sound that you hear stops.

Instruction for accuracy condition

See these targets. Try to hit them as many times as you can when you hear the buzzer. Now, remember, be sure to hit the targets and keep tapping until the sound stops.

Instructions for speed condition

See these targets. Try to hit them as many times as you can when you hear the buzzer. Go as fast as you possibly can. Now, remember, hit them as fast as you can and keep tapping until the sound stops.

APPENDIX B

Analysis of Variance for Rate of Performance Dependent Variable

Source	Error Term	S.S.	d.f.	M.S.	F
Mean	P(QAS)	41300.22	1	41300.22	574.52
Q	P(QAS)	412.83	1	412.83	5.74*
A	P(QAS)	322.90	1	322.90	4.49*
S	P(QAS)	.29	1	.29	.004
I	PI(QAS)	1017.40	1	1017.40	19.03*
L	PL(QAS)	391.90	2	195.95	10.12*
T	PT(QAS)	7.54	4	1.89	.22
QA	P(QAS)	72.00	1	72.00	1.00
QS	P(QAS)	17.74	1	17.74	.25
AS	P(QAS)	134.77	1	134.77	1.87
QI	PI(QAS)	4.57	1	4.57	.09
AI	PI(QAS)	125.99	1	125.99	2.35
SI	PI(QAS)	23.98	1	23.98	.45
QL	PL(QAS)	80.60	2	40.30	2.08
AL	PL(QAS)	56.43	2	28.22	1.46
SL	PL(QAS)	343.18	2	171.59	8.86*
IL	PIL(QAS)	806.39	2	403.20	20.62*
QT	PT(QAS)	15.47	4	3.88	.46
AT	PT(QAS)	58.25	4	14.56	1.73
ST	PT(QAS)	16.49	4	4.12	.49
IT	PIT(QAS)	32.26	4	8.06	.94
LT	PLT(QAS)	124.74	8	15.59	1.59
QAS	P(QAS)	1.50	1	1.50	.02
QAI	PI(QAS)	383.42	1	383.42	7.17*
QSI	PI(QAS)	1.68	1	1.68	.03
ASI	PI(QAS)	44.16	1	44.16	.83
QAL	PL(QAS)	62.35	2	31.18	1.61
QSL	PL(QAS)	5.56	2	2.78	.14
ASL	PL(QAS)	206.32	2	103.16	5.33*
QIL	PIL(QAS)	79.70	2	79.70	2.04

Analysis of Variance Rate of Performance (Continued)

Source	Error Term	S.S.	d.f.	M.S.	F
AIL	PIL(QAS)	44.47	2	22.24	1.14
SIL	PIL(QAS)	76.86	2	38.43	1.97
QAT	PT(QAS)	29.49	4	7.37	.87
QST	PT(QAS)	32.76	4	32.76	.97
AST	PT(QAS)	9.48	4	2.37	.28
QIT	PIT(QAS)	18.30	4	4.58	.54
AIT	PIT(QAS)	60.44	4	15.10	1.77
SIT	PIT(QAS)	13.37	4	3.34	.39
QLT	PLT(QAS)	111.37	8	13.92	1.43
ALT	PLT(QAS)	54.81	8	6.85	.70
SLT	PLT(QAS)	101.79	8	12.72	1.30
ILT	PILT(QAS)	85.68	8	10.71	1.11
P(QAS)		5175.86	72	71.89	
QASI	PI(QAS)	26.13	1	26.12	.49
QASL	PL(QAS)	8.79	2	4.40	.23
QAIL	PIL(QAS)	19.78	2	9.89	.51
QSIL	PIL(QAS)	136.48	2	68.24	3.49
ASIL	PIL(QAS)	163.60	2	81.80	4.18
QAST	PT(QAS)	8.11	4	2.03	.24
QAIT	PIT(QAS)	28.89	4	7.22	.85
QSIT	PIT(QAS)	13.97	4	3.49	.41
ASIT	PIT(QAS)	21.99	4	5.50	.64
QALT	PLT(QAS)	37.74	8	4.71	.48
QSLT	PLT(QAS)	78.21	8	9.78	1.00
ASLT	PLT(QAS)	52.49	8	6.56	.67
QILT	PILT(QAS)	101.43	8	12.68	1.31
AILT	PILT(QAS)	57.11	8	7.13	.74
SILT	PILT(QAS)	48.95	8	6.11	.63
PI(QAS)		383.64	72	53.45	
PL(QAS)		2788.40	144	19.37	
PT(QAS)		2429.76	288	8.44	

Analysis of Variance Rate of Performance (Continued)

Source	Error Term	S.S.	d.f.	M.S.	F
QASIL	PIL(QAS)	12.87	2	6.43	.33
QASIT	PIT(QAS)	56.15	4	14.04	1.64
QASLT	PLT(QAS)	24.40	8	3.05	.31
QAILT	PILT(QAS)	119.76	8	14.97	1.55
QSILT	PILT(QAS)	54.11	8	6.76	.70
ASILT	PILT(QAS)	28.91	8	3.61	.37
PIL(QAS)		2816.16	144	19.56	
PIT(QAS)		2460.38	288	8.54	
PLT(QAS)		5625.53	576	9.76	
QASILT	PILT(QAS)	147.61	8	18.45	1.91
PILT(QAS)		5570.64	576	9.67	

Analysis of Variance for Seconds Per Hit Dependent Variable

Source	Error Term	S.S.	d.f.	M.S.	F
Mean	P(QAS)	830.86	1	830.86	
Q	P(QAS)	7.29	1	7.29	18.21*
A	P(QAS)	4.06	1	4.06	10.16*
S	P(QAS)	.062	1	.062	.16
I	P(QAS)	19.27	1	19.27	362.23*
L	PL(QAS)	9.92	2	4.96	211.34*
T	PT(QAS)	.095	4	.023	16.69*
QA	P(QAS)	2.49	1	2.49	6.23*
QS	P(QAS)	.014	1	.014	.04
AS	P(QAS)	.147	1	.147	.37
QI	PI(QAS)	.158	1	.158	2.97
AI	PI(QAS)	.414	1	.414	7.78*
SI	PI(QAS)	.105	1	.105	1.97
QL	PL(QAS)	.223	2	.111	4.74*
AL	PL(QAS)	.010	2	.005	.23
SL	PL(QAS)	.725	2	.362	15.44*
IL	PIL(QAS)	.487	2	.244	22.46*
QT	PT(QAS)	.011	4	.002	1.96
AT	PT(QAS)	.009	4	.002	1.52
ST	PT(QAS)	.002	4	.000	.39
IT	PIT(QAS)	.012	4	.002	2.03
LT	PLT(QAS)	.010	8	.001	.97
QAS	P(QAS)	.009	1	.009	.02
QAI	PI(QAS)	.001	1	.001	.02
QSI	PI(QAS)	.070	1	.070	1.33
ASI	PI(QAS)	.016	1	.016	.30
QAL	PL(QAS)	.067	2	.033	1.42
QSL	PL(QAS)	.044	2	.022	.94
ASL	PL(QAS)	.249	2	.125	5.32*
QIL	PIL(QAS)	.169	2	.084	7.80*

Analysis of Variance Seconds Per Hit (Continued)

Source	Error Term	S.S.	d.f.	M.S.	F
AIL	PIL(QAS)	.033	2	.016	1.53
SIL	PIL(QAS)	.006	2	.003	.28
QAT	PT(QAS)	.002	4	.0006	.44
QST	PT(QAS)	.011	4	.003	1.97
AST	PT(QAS)	.002	4	.0003	.28
QIT	PIT(QAS)	.0003	4	.0001	.07
AIT	PIT(QAS)	.002	4	.0004	.30
SIT	PIT(QAS)	.007	4	.002	1.20
QLT	PLT(QAS)	.011	8	.001	1.01
ALT	PLT(QAS)	.007	8	.0008	.60
SLT	PLT(QAS)	.019	8	.002	1.68
ILT	PILT(QAS)	.021	8	.003	1.83
P(QAS)		28.80	72	.40	
QASI	PI(QAS)	.063	1	.063	1.19
QASL	PL(QAS)	.008	2	.004	.17
QAIL	PIL(QAS)	.059	2	.293	2.71
QSIL	PIL(QAS)	.026	2	.013	1.22
ASIL	PIL(QAS)	.026	2	.013	1.18
QAST	PT(QAS)	.002	4	.0004	.34
QAIT	PIT(QAS)	.002	4	.0005	.41
QSIT	PIT(QAS)	.001	4	.0003	.24
ASIT	PIT(QAS)	.008	4	.002	1.40
QALT	PLT(QAS)	.009	8	.001	.79
QSLT	PLT(QAS)	.017	8	.002	1.48
ASLT	PLT(QAS)	.031	8	.003	2.79
QILT	PILT(QAS)	.015	8	.002	1.33
AILT	PILT(QAS)	.003	8	.0003	.27
SILT	PILT(QAS)	.017	8	.002	1.46
PI(QAS)		3.83	72	.053	
PL(QAS)		3.38	144	.023	
PT(QAS)		.41	288	.002	

Analysis of Variance Seconds Per Hit (Continued)

Source	Error Term	S.S.	d.f.	M.S.	F
QASIL	PIL(QAS)	.007	2	.003	.32
QASIT	PIT(QAS)	.002	4	.0006	.44
QASLT	PLT(QAS)	.016	8	.002	1.47
QAILT	PILT(QAS)	.008	8	.001	.67
QSILT	PILT(QAS)	.008	8	.001	.69
ASILT	PILT(QAS)	.017	8	.002	1.47
PIL(QAS)		1.56	144	.011	
PIT(QAS)		.41	288	.001	
PLT(QAS)		.80	576	.001	
QASILT		.008	8	.001	.66
PILT(QAS)		.835	576	.001	

Analysis of Variance for Correct Hits Per Second Dependent Variable

Source	Error Term	S.S.	d.f.	M.S.	F
Mean	P(QAS)	5373.02	1	5373.02	
Q	P(QAS)	34.03	1	34.03	24.36*
A	P(QAS)	8.19	1	8.19	5.86*
S	P(QAS)	.73	1	.73	.52
I	PI(QAS)	11.86	1	11.86	57.78*
L	PL(QAS)	270.35	2	135.17	331.26*
T	PT(QAS)	.19	4	.05	2.23
QA	P(QAS)	8.33	1	8.33	5.96*
QS	P(QAS)	.15	1	.15	.11
AS	P(QAS)	.44	1	.44	.31
QI	PI(QAS)	.02	1	.02	.10
AI	PI(QAS)	.49	1	.49	2.39
SI	PI(QAS)	.21	1	.21	1.03
QL	PL(QAS)	1.63	2	.82	2.01
AL	PL(QAS)	1.42	2	.72	1.74
SL	PL(QAS)	3.51	2	1.76	4.30*
IL	PIL(QAS)	15.32	2	7.66	94.64*
QT	PT(QAS)	.11	4	.03	1.28
AT	PT(QAS)	.07	4	.02	.84
ST	PT(QAS)	.12	4	.03	1.34
IT	PIT(QAS)	.18	4	.04	1.62
LT	PLT(QAS)	.29	8	.04	1.33
QAS	P(QAS)	.07	1	.07	.05
QAI	PI(QAS)	1.24	1	1.24	6.01*
QSI	PI(QAS)	.27	1	.27	1.30
ASI	PI(QAS)	.14	1	.14	.66
QAL	PL(QAS)	1.81	2	.91	2.22
QSL	PL(QAS)	.60	2	.30	.74
ASL	PL(QAS)	1.87	2	.93	2.29
QIL	PIL(QAS)	1.37	2	.69	8.47*

Anaysis of Variance Correct Hits Per Second (Continued)

Source	Error Term	S.S.	d.f.	M.S.	F
AIL	PIL(QAS)	.03	2	.02	.19
SIL	PIL(QAS)	.42	2	.21	2.59
QAT	PT(QAS)	.15	4	.04	1.73
QST	PT(QAS)	.10	4	.03	1.19
AST	PT(QAS)	.10	4	.03	1.13
QIT	PIT(QAS)	.07	4	.02	.68
AIT	PIT(QAS)	.18	4	.04	1.61
SIT	PIT(QAS)	.08	4	.02	.78
QLT	PLT(QAS)	.08	8	.01	.36
ALT	PLT(QAS)	.08	8	.09	.34
SLT	PLT(QAS)	.19	8	.02	.86
ILT	PILT(QAS)	.20	8	.03	.89
P(QAS)		100.59	72	1.40	
QASI	PI(QAS)	.08	1	.08	.39
QASL	PL(QAS)	.19	2	.10	.24
QAIL	PIL(QAS)	.09	2	.04	.54
QSIL	PIL(QAS)	.48	2	.24	2.95
ASIL	PIL(QAS)	.06	2	.03	.39
QAST	PT(QAS)	.15	4	.04	1.70
QAIT	PIT(QAS)	.16	4	.04	1.49
QSIT	PIT(QAS)	.02	4	.006	.22
ASIT	PIT(QAS)	.18	4	.04	1.62
QALT	PLT(QAS)	.37	8	.05	1.68
QSLT	PLT(QAS)	.21	8	.03	.93
ASLT	PLT(QAS)	.69	8	.09	3.13
QILT	PILT(QAS)	.14	8	.02	.64
AILT	PILT(QAS)	.25	8	.03	1.11
SILT	PILT(QAS)	.08	8	.01	.36
PI(QAS)		14.79	72	.21	
PL(QAS)		58.76	144	.41	
PT(QAS)		6.28	288	.02	

Analysis of Variance Correct Hits Per Second (Continued)

Source	Error Term	S.S.	d.f.	M.S.	F
QASIL	PIL(QAS)	.15	2	.08	.94
QASIT	PIT(QAS)	.04	4	.01	.40
QASLT	PLT(QAS)	.60	8	.02	.60
QAILT	PILT(QAS)	.28	8	.04	1.25
QSILT	PILT(QAS)	.22	8	.03	1.02
ASILT	PILT(QAS)	.18	8	.02	.81
PIL(QAS)		11.65	144	.08	
PIT(QAS)		7.86	288	.03	
PLT(QAS)		15.80	576	.03	
QASILT	PILT(QAS)	1.06	8	.03	1.06
PILT(QAS)		15.86	576	.03	

Analysis of Variance for Errors Per Second Dependent Variable

Source	Error Term	S.S.	d.f.	M.S.	F
Mean	P(QAS)	356.65	1	356.65	159.53
Q	P(QAS)	7.50	1	7.50	3.35
A	P(QAS)	11.45	1	11.45	5.12*
S	P(QAS)	.64	1	.64	.29
I	PI(QAS)	119.19	1	119.19	133.66*
L	PL(QAS)	43.49	2	21.74	77.73
T	PT(QAS)	1.00	4	.25	10.61*
QA	P(QAS)	16.92	1	16.92	7.57*
QS	P(QAS)	.05	1	.05	.02
AS	P(QAS)	.004	1	.004	.002
QI	PI(QAS)	2.86	1	2.86	3.21
AI	PI(QAS)	1.03	1	1.03	1.17
SI	PI(QAS)	.18	1	.18	.20
QL	PL(QAS)	.82	2	.41	1.46
AL	PL(QAS)	.97	2	.48	1.73
SL	PL(QAS)	3.21	2	1.61	5.74*
IL	PIL(QAS)	9.71	2	4.85	40.29*
QT	PT(QAS)	.24	4	.06	2.52
AT	PT(QAS)	.10	4	.03	1.07
ST	PT(QAS)	.62	4	.02	.65
IT	PIT(QAS)	.30	4	.08	2.82
LT	PLT(QAS)	.18	8	.02	.88
QAS	P(QAS)	.005	1	.005	.002
QAI	PI(QAS)	8.84	1	8.84	9.91*
QSI	PI(QAS)	.26	1	.26	.29
ASI	PI(QAS)	.26	1	.26	.29
QAL	PL(QAS)	1.47	2	.73	2.62
QSL	PL(QAS)	.09	2	.05	.17
ASL	PL(QAS	.21	2	.10	.37
QIL	PIL(QAS)	.45	2	.23	1.88

Analysis of Variance Errors Per Second (Continued)

Source	Error Term	S.S.	d.f.	M.S.	F
AIL	PIL(QAS)	.42	2	.21	1.74
SIL	PIL(QAS)	2.18	2	1.09	9.06*
QAT	PT(QAS)	.27	4	.07	2.84
QST	PT(QAS)	.21	4	.05	2.20
AST	PT(QAS)	.09	4	.02	.99
QIT	PIT(QAS)	.10	4	.25	.93
AIT	PIT(QAS)	.15	4	.04	1.38
SIT	PIT(QAS)	.03	4	.008	.31
QLT	PLT(QAS)	.24	8	.03	1.17
ALT	PLT(QAS)	.07	8	.009	.35
SLT	PLT(QAS)	.20	8	.03	.97
ILT	PILT(QAS)	.30	8	.04	1.61
P(QAS)		160.96	72	2.24	
QASI	PI(QAS)	.0008	1	.0008	.0009
QASL	PL(QAS)	.015	2	.008	.02
QAIL	PIL(QAS)	.63	22	.31	2.61
QSIL	PIL(QAS)	.02	2	.009	.08
ASIL	PIL(QAS)	.13	2	.06	.52
QAST	PT(QAS)	.13	4	.03	1.40
QAIT	PIT(QAS)	.14	4	.03	1.29
QSIT	PIT(QAS)	.08	4	.02	.75
ASIT	PIT(QAS)	.02	4	.004	.15
QALT	PLT(QAS)	.29	8	.04	1.44
QSLT	PLT(QAS)	.22	8	.03	1.06
ASLT	PLT(QAS)	.31	8	.04	1.51
QILT	PILT(QAS)	.10	8	.01	.50
AILT	PILT(QAS)	.23	8	.03	1.20
SILT	PILT(QAS)	.12	8	.01	.59
PI(QAS)		64.21	72	.89	
PL(QAS)		40.28	144	.28	
PT(QAS)		6.81	288	.02	

Analysis of Variance Errors Per Second (Continued)

Source	Error Term	S.S.	d.f.	M.S.	F
QASIL	PIL(QAS)	.06	2	.03	.24
QASIT	PIT(QAS)	.94	4	.02	.94
QASLT	PLT(QAS)	.15	8	.02	.75
QAILT	PILT(QAS)	.16	8	.02	.84
QSILT	PILT(QAS)	.20	8	.03	1.07
ASILT	PILT(QAS)	.23	8	.03	1.19
PIL(QAS)		17.34	144	.12	
PIT(QAS)		7.64	288	.03	
PLT(QAS)		14.68	576	.03	
QASILT	PILT(QAS)	.25	8	.03	1.33
PILT(QAS)		13.65	576	.03	